DEVELOPMENT AND PERFORMANCE EVALUATION OF A ROTARY TILLAGE ATTACHMENT TO THE K.A.U. GARDEN TRACTOR

By

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THESIS

Submitted in partial fulfilment of
the requirement for the degree

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Tavanur Malappuram

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DECLARATION

I hereby declare that this thesis entitled "Development and Performance Evaluation of a Rotary Tillage Attachment to the KAU Garden Tractor" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled "Development and Performance Evaluation of a Rotary Tillage Attachment to the KAU Garden Tractor" is a record of research work done independently by **Shri. Jose, C.M.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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JOSE, C.M.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS USED

cm	-	centimetre(s)
Co.	-	Company
Dept.	-	Department
dia	-	diameter
edn	-	edition
et al.	-	and other people
Fig.	-	Figure
gm	-	gram(s)
ha	-	hectare(s)
hp	-	horse power
hr	-	hour(s)
ICAR	-	Indian Council of Agricultural Research
ISAE	-	Indian Society of Agricultural Engineers
J	-	Journal
JNKVV	-	Jawaharlal Nehru Krishi Viswa Vidhyalay
kg	-	kilogram(s)
kgf	-	kilogram force
kmph	-	kilometres per hour
lit	-	litre(s)
m	-	metre(s)
min	-	minute
mm	-	millimetre(s)
MS	-	Mild Steel

No.	-	number
p	-	page
pp	-	pages
proc.		proceedings
Pvt.	-	Private
rpm	-	revolutions oper minute
Rs	-	rupees
sec	-	second
TNAU	-	Tamil Nadu Agricultural University
/	-	per
%	-	per cent
π	-	pi (22/7)
λ	-	Kinamatic index
β	-	rake angle
ϕ	-	edge curve

Introduction

INTRODUCTION

Mechanisation of agriculture is a must not only for higher productivity, but also for reducing the cost of production. On the basis of extensive studies carried out in different parts of the country, it has been found that the use of selective mechanisation results in 7.5 to 40 per cent increase in agricultural productivity (Singh *et al*., 1984).

Considering the various aspects, agricultural mechanisation in India has to be need-based, selective, low cost, appropriate, input oriented and labour intensive. It is unlikely that there will be replacement of any particular source of power in the years to come.

The power availability for agricultural purposes in India is around 0.75 to 0.80 hp per ha against the minimum recommended level of 1 hp per ha required on a single cropping basis. Countries having 3 to 4 times higher yields have ensured 3 to 4 hp per ha of power to agriculture. In our country dry land agriculture constituting 70 per cent of the cropped area and producing only 30 per cent of food, holds the key to growth in agricultural production, but this will require a much higher power input (Mehta, 1989).

In India more than 90 per cent of farm holdings are under 5 ha in size. The predominance of the small holdings had been considered as a serious problem for mechanisation. But Japan, Taiwan and South Korea have proved that small size of holdings does not hinder farm mechanisation (Singh, 1989).

Human beings and bullocks as sources of energy, are not only inadequate but also costly. An energy survey in village Pamali in Ludhiana district has shown that human energy is 15 to 20 times costlier than energy produced by a diesel engine or an electric motor.

The small power operated and low cost agricultural machines are found to be most suitable and it would have maximum annual use. Unlike a large tractor, these machines would replace animals but not people and would help country's objectives of promoting economic development, better income distribution and employment. Imported machines and even unaltered foreign designs are seldom appropriate for the small farmers as they find it too sophisticated and costly.

As per the reports of the survey of the ICAR co-ordinated scheme on power tillers, the non-adoption of power tillers by farmers was mainly due to the unavailability of low cost power tillers in the range of 5 to 7 hp with matching implements.

Kerala Agricultural University had developed a 5.4 hp diesel powered low cost garden tractor for the general use of small farmers (Sivaswami, 1982). Realising the need of matching implements to make this garden tractor a versatile farm power unit it was decided to develop a rotary tillage attachment.

Moreover the advantages of rotary tillers compared to non-powdered tillage implements are so many. A high quality of soil cultivation and uniform mixing of the soil with plant residues and organic and mineral fertilizers can be achieved with rotary tillers. Rotary tillers attached to power tillers can be used to prepare soil under tree crowns, in stem regions and in inter-rows. Inter-row rotary cultivation gives a high quality of soil crumbling and weed destruction and is particularly effective in heavy loamy and soddy soils. Rotary cultivation has a positive effect on the physical properties of the soil, on water and on the nutrient regimes of plants. The reduced tractive resistance of rotary tillers makes them ideally suited to couple with light tractors and power tillers.

It was therefore decided to undertake the study of development of a rotary tillage attachment to the light weight, 5.4 hp KAU garden tractor with the following objectives.

1. Design and fabricate the machine
2. Test the implement in dry field conditions for its performance evaluation
3. Modify the implement if necessary
4. Workout the economics of operation

Review of Literature

REVIEW OF LITERATURE

A brief review of tillage equipments and history and development of rotary soil working tools are given in this chapter.

2.1 Tillage equipments

Tillage may be described as the practice of modifying the state of the soil in order to provide conditions favourable to crop growth. The primary objectives and fundamental purposes of tillage are divided into three phases, viz.,

1. to prepare a suitable seed bed,
2. to destroy competitive weeds and
3. to improve the physical condition of the soil.

2.1.1 Classification of tillage equipments

Tillage equipments can be divided into two general classes viz.,

1. primary tillage equipments and
2. secondary tillage equipments

Equipment that is used to break deeply and loosen the soil for preparing a suitable seed bed may be considered as primary tillage equipment. It includes the mould board, disc, rotary, chisel and subsoil ploughs.

Secondary tillage is the stirring of soil at comparatively shallow depths. The general objectives and functions of secondary tillage implements are:

1. to improve the seed bed by greater pulvarisation of the soil
2. to conserve moisture by summer-fallow operations, to kill weeds and to reduce evaporation
3. to cut crop residue and cover crops and to mix vegetable matter with the top soil
4. to break up clods, firm the top soil and put it in better tilth for seeding and germination of seeds, and
5. to destroy weeds on fallow lands.

There are many types of machines that can be used for secondary tillage operations. They are the various types of harrows, cultivators, rollers and pulvarizers. Rotary cultivators are also used for secondary tillage as they are capable of producing a seed bed in fewer operations.

2.1.2 Common secondary tillage implements

2.1.2.1 Harrows

Harrows consist of small tynes which break down the soil on impact and also cause consolidation of the lower layers. Their working depth is about 150 mm and they may consist of either rigid or spring tynes. The tynes are mounted on a frame and the number of frames depends on the size of the tractor pulling it. The frame has a levelling action as it is drawn over the soil. There are usually about 20 tynes on a frame. The frames are fastened to a pole which is pulled by the tractor. The common types of harrows are listed below with brief description.

2.1.2.1.1 Disc harrows

Disc harrows have a number of saucer-shaped discs mounted on one, two or more axles, which may be set at a variable angle to the line of draught. The discs are generally from 457 to 610 mm in diameter. They rotate as the harrow is pulled along and their action on the soil is like that of small digging type ploughs. The precise action however depends on the size of the discs, the depth of work and especially upon the angle at which the disc gangs are set relative to the line of travel. As a general rule disc implements are arranged to work with the gangs set at angles varying from about 15 to 25 degrees. The main use of disc harrows is in the preparation of seed beds in conditions where the tyned implements are either ineffective or can not be employed because of pulling of the buried turf, rubbish or manure out of the soil. Discs have a consolidating effect on the lower parts of the furrow slices that may be very valuable in certain circumstances. For a good, firm seed bed it is required to use the discs both along and across the furrows. Disc harrows have few disadvantages, chief being a rather higher cost and rate of depreciation than most tyned implements and certain amount of difficulty with transport. The transport difficulty may be overcome by the use of road wheels with a hydraulic control gear to raise the impplement out of work.

2.1.2.1.2 Spike tooth harrow

In a spike-tooth harrow the teeth that stir the soil resemble long spikes. This harrow is also known as peg tooth harrow, drag harrow, section harrow or smoothing harrow. Its principal use is to smoothen and level the field directly after ploughing. The sections may range in width from 120 to 175 cm and may have twenty five, thirty or thirty five teeth. Several sections may be attached to a hitch bar of a wide swath harrow. The sections may be either rigid or flexible.

Sections having guard rails across the ends of the bars are called closed end harrows, while those without guard rails are called open end harrows.

2.1.2.1.3 Spring tyned harrows

The spring tyned harrow is really a light cultivator which can be adjusted to produce variable effects on soil. They are adopted for use in rough and stony ground. They are also used extensively to loosen previously ploughed soil just prior to the seeding of rice or small grains. The tynes are fitted to axles which can be partially rotated by means of a lever. With the implement working very shallow the points are almost vertical and the action is that of a light harrow that does not penetrate to the lower layers. When set in an intermediate position the points are inclined, and the action is that of a light cultivator. At full depth the points are almost horizontal and the soil is deeply stirred.

2.1.2.2 Rotary cultivators

Rotary cultivators have now become accepted as cultivation implements for both farm work and horticulture in several countries. Rotary cultivators of conventional type are now used for a variety of farm jobs including the first working with stubble after harvesting. Their use for seed-bed preparation in general farming is increasing.

When a tractor is pulling a plough a proportion of the power is lost in its transmission from the engine to the implement drawbar. Rotary cultivators waste less power in this way. They are often complementary to traditional implements such as ploughs and it is a mistake to regard rotary cultivation simply as an alternative to ploughing. Rotary cultivators can be either tractor mounted type or self propelled pedestrain operated type.

2.1.2.2.1 Tractor mounted rotary cultivators

Large tractor mounted power take-off driven rotary cultivators are available where large areas are to be ploughed. A wide range of effects can be produced by varying the forward speed, the rotor speed and the number of blades on the rotor shaft as well as adjustment of the rear cover.

2.1.2.2.2 Pedestrian operated rotary cultivators

There are many pedestrian operated small rotary cultivators in the market with four stroke engine as their source of power. The rotor is a shaft on which are bolted, a series of detachable L-shaped blades. Around the rotor is a shield which controls the quality of tilth produced and protects the operator from flying stones and clods. The blades rotate in the direction of forward travel and cut out slices of soil which are pulvarised against the shield and by other blades.

2.2 History of rotary soil working tools

Rotary tillers were first developed in Japan about 50 years ago.

Smith (1955) reported the features of three different types of rotary ploughs. They were the pull auxiliary engine type, the pull power take-off driven type and the self propelled garden type.

(a) Pull auxiliary engine rotary plough

It is a rotary plough which is pulled forward by a tractor. Its cutting knives are driven by an auxiliary engine mounted on the frame of the plough. The cutting knives are mounted on a horizontal power driven shaft. He also reported the availability of tractor mounted auxiliary engine driven rotary cultivators.

(b) Pull power take off driven rotary plough

This machine is not only pulled forward by the tractor but has the cutting knives also driven by the tractor. This type is usually 90 to 120 cm wide and requires 10 to 15 hp for 30 cm width. The cutting knives or tynes are generally mounted on a horizontal power-driven shaft which operates at about 300 rpm. The knives of some machines are provided with a shock-cusioned friction clutch that prevents the knives from breaking when they come in contact with a rock or solid obstacle.

(c) Self propelled garden type rotary plough

Some of the garden type rotary ploughs have one drive wheel, while others have two (Fig.1). They plough a strip of 25 to 75 cm width and are powered by 6 to 15 hp engines. They can be operated at two speeds forward-low 0.8 to 1.6 km/h high 1.6 to 3.5 km/h. The reverse speed is 1.2 to 2.4 km/h. Some garden type rotary ploughs can also be used for cultivating vegetable crops. The narrow width of 42.5 cm or less makes it possible to plough nararow strips in a garden.

Sakai in 1956 started his agricultural engineering research on a hand tractor with a rotary tiller and this research led him to get the design principles for a better hand tractor equipped with a rotary tiller. This machine is called rotary power tiller in Japan (Sakai, 1962).

Yatsuk *et al*. (1971) enumerated the basic functional requirements of a rotary tiller as:

1. they should be able to till the soil in the strips close to tree trunks and in the rows between the trees with continuous straight motion of the unit.

2. they should have an adjustment for depth of ploughing within the range 6 to 20 cm

3. they should completely destroy weeds and break up green manure crops and mix them with the soil

4. they should not damage the roots or branches of fruit trees and bushes.

They reported the technical specifications of rotary garden tillers which were used in USSR at that time (Table 1).

Yatsuk *et al*. (1971) emphasised the use of miniature rototillers for soil working in vegetable farms, nurseries, greenhouses and on lawns. They classified the miniature rototillers as (i) manual with electric drive, (ii) manual with a flexible drive shaft from a portable engine carried on the shoulders and, (iii) manual with engine mounted directly over the cutter drum.

Table 1 Technical specifications of garden tillers

Index	Model country and firm								
	FP 2 USSR	FM 2 USSR	FSN 0 9 USSR	FLR 1 10 Bulgaria	Nardi Italy	FS 0 9 USSR	FS 0 6 USSR	FSP 1 2 USSR	G Ferri Italy
Type of machine	Mounted	Mounted	Semi Mounted	Semi Mounted	Semi Mounted	Semi-Mounted	Semi Mounted	Semi Mounted	Trailed
Cutting width, m	1 3–2	1 5–2	0 9	1 1	0 85	0 9	0 6	1 2	0 6
Depth of working, cm	Up to 12	Up to 8	6 11	Up to 12	Up to 10	Up to 10	Up to 10	Up to 12	Up to 12
Diameter of cutter drum, mm	450	225	570	440	450	400	600	450 horizontal drum, 470 vertical drum	335
RPM of drum	196	400; 510, 605	403	210	160, 270	220	70, 80, 100	180, 220	540
Forward speed, km/hr	6 0	3–5	4–5	1 3–3 6	1 5–2 5	2 8	3–5	3–5	1 5–2 0
Specific metal content, kg/m	250	200	380	240	265	400	500	270	650
Power requirement, hp	40	40	15–20	20–30	20–35	10–15	15–20	35	5–10
Extension to side from tractor axis m	Up to 1 6	None	2 4	None	1 0	Up to 2 8	Up to 3 5	3 2	Up to 2 6

The features of the FOP-1 miniature rototiller (Fig.2) which gets the drive from a 3 hp gasoline engine were listed by Yatsuk et al. (1971). Its cutter units consisting of a flange and four cutters rivetted to the flauge, were mounted on the ends of the worm gear. Two cutter units were mounted for working a 10.0 cm wide space between rows. Four cutter units were used when this width is 20.0 cm. The cutting width of the cutters was 3.5 cm. The cutters on adjacent cutter units were displaced through 4.5 degrees. It employed a centrifugal friction clutch made in two halves. The special feature of this clutch was that it engaged only when the engine reaches the working speed. The major defect of this machine was the difficulty of controlling feed per cutter.

The special features of the PMA miniature tiller reported by Yatsuk et al. (1971) were (i) automatic engagement of the cutter drum through a centrifugal cluth, (ii) belt drive in the torque transmission system of the cutter drum and (iii) use of motorcycle-type wheels in the traction system of the tiller (Fig.3). Reports on testing of this rototiller revealed that the cutter could not meet the agrotechnical requirements.

Yatsuk et al. (1971) reported the features of an electric driven miniature tiller (EM-12 electric hoe) used in greenhouses, seed beds and ridges with compacted earth (Fig.4).

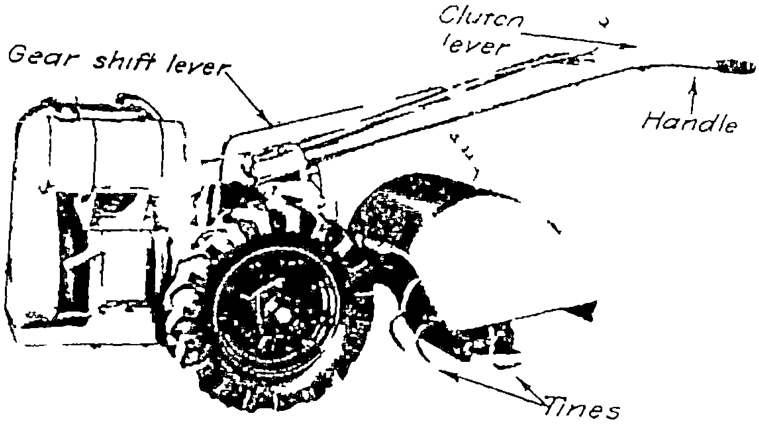
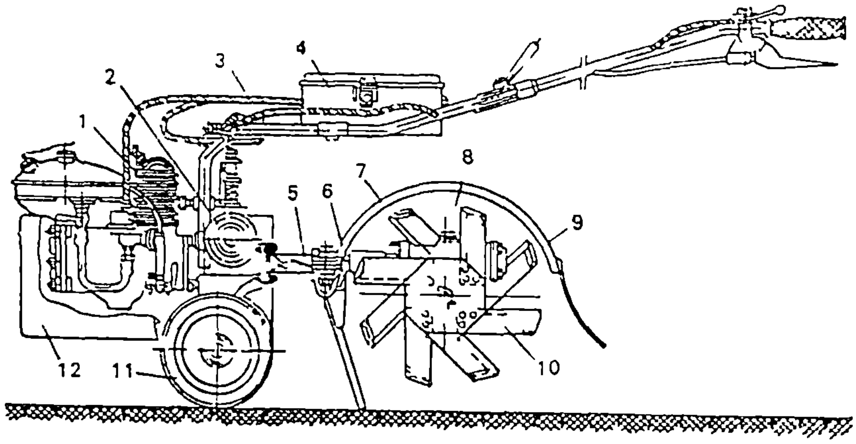
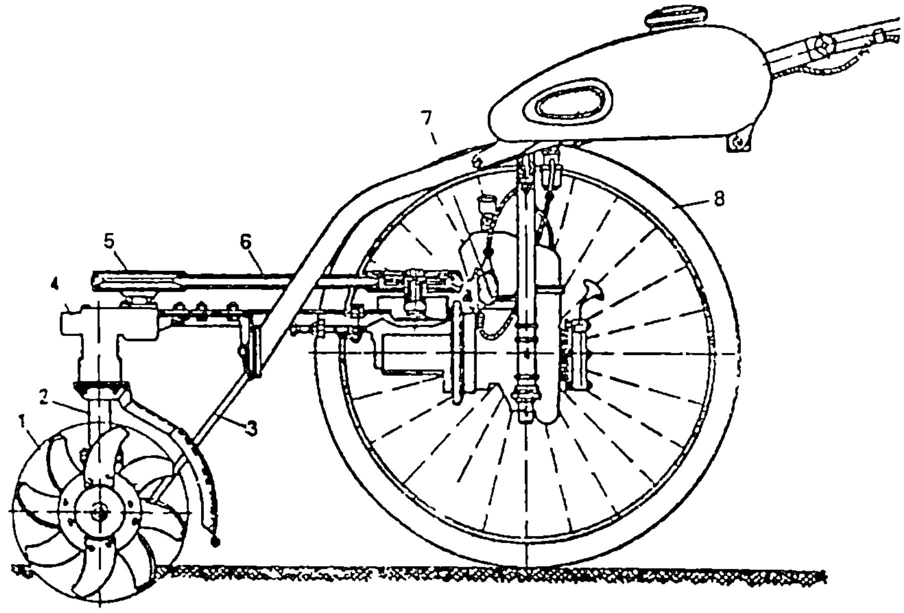


Fig.1 Garden tractor type rotary plough (Smith, 1955)



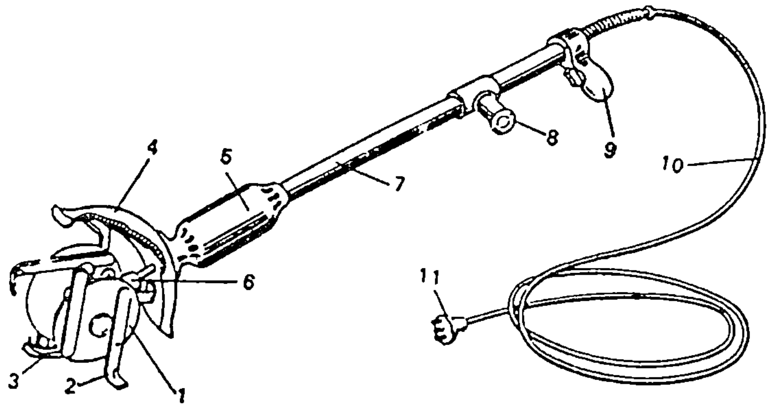
1—engine, 2—intermediate shaft with clutch 3—control mechanism 4—instrument box 5—connecting shaft, 6—pipe of gearbox 7—protective casing, 8—worm gear 9 10—cutters 11—wheel 12—deflector

Fig.2 FOP-I miniature rototiller (Yatsuk, 1971)



1—cutter drum *2*—vertical shaft *3*—thrust bar *4*—reduction gear
5—pulley *6*—belt drive *7*—Druzhba engine *8*—supporting wheel

Fig.3 PMA miniature tiller (Yatsuk, 1971)



1—disc of cutter drum, *2* and *3*—cutters *4*—cover *5*—electric motor
6—reduction gear; *7*—carrying pipe *8* and *9*— handles *10*—cable *11*—plug

Fig.4 EM-12 electric hoe (Yatsuk, 1971)

It consists of a rotor with a reduction gear and housing,a bar handle and a 0.4 kw electric motor. The cutting width of electric hoe is 12 cm average depth of working was 10 cm and output was 150 m^2/hr.

Miniature tillers were widely used in England, Japan, Germany and Italy. The miniature rototillers which were produced in England were driven by single axle tractors of 9, 11 and 15 hp rating through a single disc dry clutch, reduction gear and chain drive (Yatsuk et al., 1971).

The features of the Land master 150 tillers were also reported by Yatsuk et al. (1971). The cutter drum of the Land master 150 had the speeds, 120, 250 and 350 rpm. The forward speeds of this tiller are 0.8 and 2.4 km/hr and its weight is 114 kg. Technical specifications of many other rotary tillers where also reported by them and they are presented in Table 2.

Culpin (1976) reported that most of the rotary cultivators used in Britain have L-shaped blades which are normally mounted with three right-hand and three left-hand blades per flauge, but coarser work may be done by using only two right-hand and two left-hand blades per flauge (Fig.5). According to him the other factors affecting the tilth

Table 2. Technical specifications of foreign miniature tillers

Index	FS-0 7A (USSR)	EM 12 (USSR)	FOP 1 (USSR)	MPS (USSR)	Howard 300 England Howard	H, USA Allen Planet	T 100 USA Atlas
Cutting width m	0 7	0 012	0 1–0 2	0 4	0 4–0 5	Up to 0 254	Up to 0 66
Working speed km/hr	1 0	Up to 1 0	Up to 2	Up to 2	0 95–3 2	2 4–5 6	2 4
Depth of soil cutting cm	6–24	Up to 10	Up to 8	Up to 12	Up to 15	Up to 10	Up to 15
Cutter drum diameter mm	420	—	270	340	300	—	—
Speed of cutter drum rpm	200	200	322	290	—	—	75
Number of carriage wheels	2	—	2 (metallic)	2 (motor cycle type)	2	2	2
Driving unit	Electric motor AO-42-4	Electric motor	Engine RB 50	Engine RB 50	Diesel engine	Gasoline engine	Gasoline engine
Engine power kW	2 8	—	3 0	3 0	4 3–4 5	—	—
Engine speed rpm	1,420	—	4 800	4,800	2,800–3 600	—	—
Output m²/hr	420–660	Up to 200	Up to 300	Up to 400	Up to 800	Up to 1 000	Up to 500
Dimensions of tiller mm							
length	1,790	1 500	1 575	1,650	—	—	—
width	770	135	300	720	—	—	—
height	1,000	220	780	930	—	—	—
Weight kg	140	7 (45*)	28	35	104	257	54 6

Index	L5/L7 FRG, Frei Gobit	3D, FRG, Haimbyher	Type 20 GDR	KS (Japan Izeki)	KT 500 (Japan Izeki)	F 60, Japan Honda	TS-40 Japan Sato
Cutting width m	0 4–0 8	0 15–0 30	0 50–0 65	0 4	0 42	0 40	0 40
Working speed km/hr	0 9–4 24	1–5	1 2 2 5	—	—	Up to 15	Up to 0
Depth of soil cutting, cm	Up to 30	Up to 15	Up to 25	Up to 12	Up to 12	Up to 20	Up to 18
Cutter drum diameter mm	550	300	420	—	—	—	—
Speed of cutter drum, rpm	—	—	275	—	—	—	—
Number of carriage wheels	1	1	2	2	2	2	2
Driving unit	Diesel engine			Gasoline engine	Gasoline engine		
Engine power kW	5 7	1 2	4 0	3 5	5 0	4 0	4 0
Engine speed rpm	2 800	3 000	3 000	—	—	—	—
Output, m²/hr	Up to 1 000	Up to 800	Up to 1,000	Up to 1 000	Up to 1 000	Up to 1 000	Up to 1 000
Dimensions of tiller mm							
length	—	—	—	1 580	1 650	1 643	1 750
breadth	—	—	—	580	730	625	650
height	—	—	—	1,060	900	1 100	1 100
Weight, kg	350	38 (14**)	175	68	145	85	95

*Weight of tiller with step down transformer and cable

**Weight of engine carried on shoulders

produced are forward speed in realtion to rotor speed and adjustment of the rear shield.

He reported the availability of a small rotary cultivator with offset handle position which was ideally suited for row crop work.

A 5.4 hp diesel powered low cost power tiller with a rotary tilling unit (Fig.6) suitable for hilly regions with field capacity of 0.41 ha per day of 8 hours of actual ploughing operation was developed at Coimbatore (TNAU, 1980).

A bullock drawn power tiller with a 10 hp engine for powering the soil working tool was developed at Jabalpur (Pandey et al., 1983). The machine consists of a pair of wheels, engine, power transmission system, rotary tiller and a seat for the operator. The power from engine was transmitted to the rotary tiller through a telescopic shaft with universal joints and a set of bevel gears. The operator can adjust the depth of operation and lift the rotary tiller off the ground for transportation with the help of a lever from his seat itself (Fig.7).

In Jabalpur itself a walking type module rotary tiller for secondary tillage and intercultural operations was developed (Pandey et al., 1983). The unit was a self-propelled one with a 5.4 hp diesel engine. For transmission

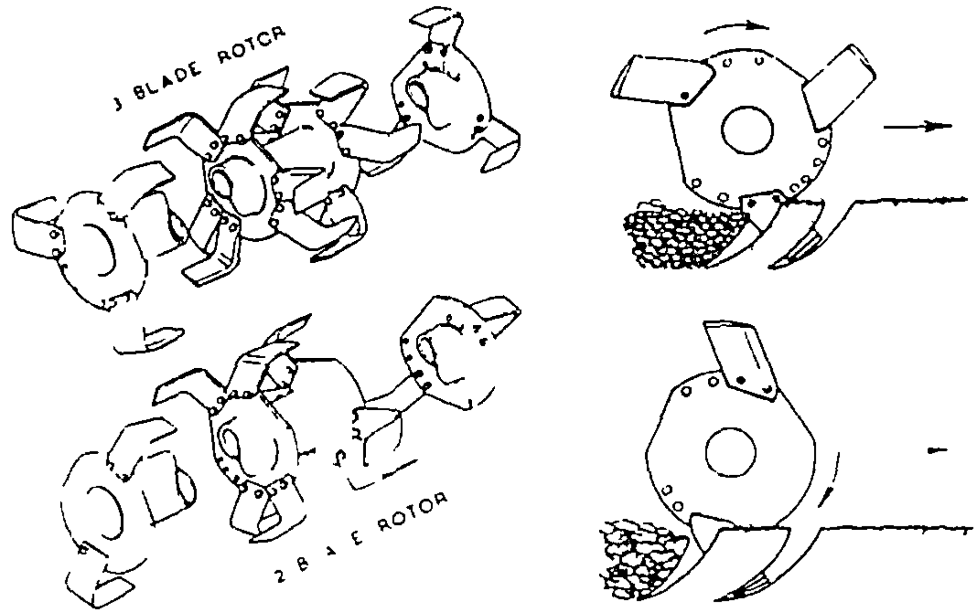


Fig.5 L-shaped rotary cultivator blades (Culpin, 1976)

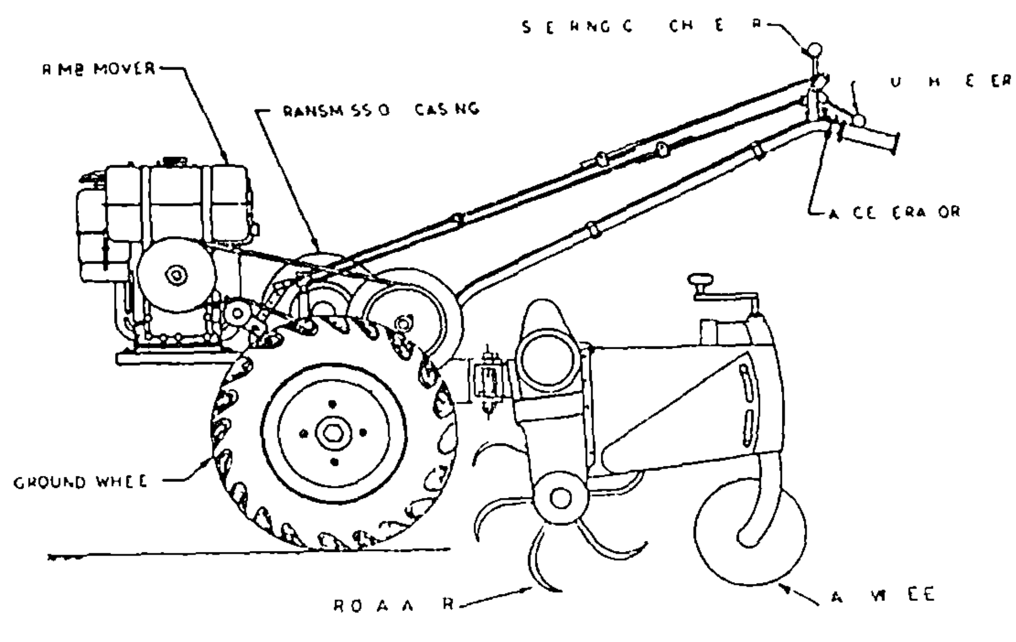
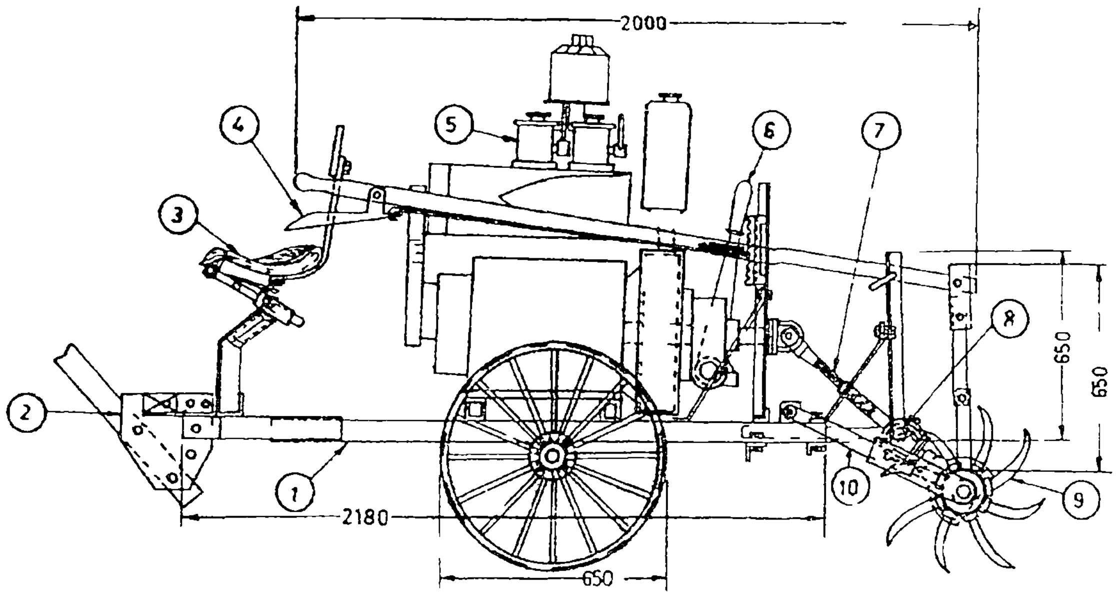


Fig.6 TNAU low cost power tiller (TNAU, 1980)



(1) FRAME
(2) CLEVIS
(3) SEAT
(4) ROTARY HEIGHT ADJUSTING LEVER
(5) 10 hp ENGINE
(6) CLUTCH LEVER
(7) PROPELLER SHAFT
(8) UNIVERSAL JOINT
(9) POTAVATOR ASSEMBLY
(10) TELESCOPIC SIDE ARMS

ALL DIMENSIONS IN mm

Fig.7 Bullock drawn power tiller (Pandey, 1983) of power to the rotary tiller, pulley and chain arrangement was provided. A gear shifting lever was provided for speed adjustment. The speed of the rotary tiller was 300 rpm. Its work capacity was found to be 0.05 ha per hr. The rotary tiller of this machine was fitted in the front side of the transport wheels. On testing the machine it was found suitable for all types of soil under dry conditions and crops like maize and soybean.

Hawker and Keenlyside (1985) found that rotary cultivators which are capable of producing a seed-bed in fewer operations than ploughing followed by normal cutivations were widely being used in horticulture as an alternative to ploughing. The features of a pedestrian operated rotor driven cultivator given by them were as follows. On machines not fitted with drive wheels the type of tilth produced depends on the operator holding back the machine or pressing down on to the rear foot. On hard ground quite a considerable amount of back pull may be required otherwise the rotors will simply push the machine forward too quickly and may not produce a proper tilth.

Power tiller with rotavator was tested in the field after harvesting of sugar cane crop for finding its efficiency in stubble removal operation at Rahuri (Annual Report, 1986). Considering the aspects like cost of operation timeliness of operation and the effectiveness of stubble removal, the power tiller with rotavator was found to be more efficient when compared to the tractors and bullocks. It was also found that no other additional operation was required after the use of rotavator for field preparation in the sugarcane fields.

Studies conducted at Himachal Pradesh with power tiller operated rotavator showed that the seed bed preparation by operating the rotavator twice was most economical and profitable as compared to the other traditional methods. The power tiller with rotavator was recommended as an alternate source of power for hilly terrains instead of bullock power (Annual Report, 1986).

Most of the rotary tiller reviewed in the history of rotary tillers where found to be highly sophisticated and costlier. It demands the need for development of a low cost rotary tiller unit for general use of the small farmers in the country.

2.3 Design considerations of rotary tillers

Yatsuk et al. (1971) developed a nomograph which is a graphical representation of the co-relation between the parameters and the working regimes of rototillers. This nomograph relates the basic parameters R, λ and V_n with the remaining parameters S, Z, n, V_t and hr.

where,

R - radius of the circle described by the cutter edge during rotation

λ - ratio of the rotary and translatory velocities of motion $= Vn/V_t$

V_n - velocity of the relative rotary motion of the working tool around the axis of the cutter drum

V_t - velocity of the translatory forward motion of the working tool

S - feed per cutter

Z - number of cutting teeth on one side of the disc

n - the rpm of the cutter drum

hr - height of the ridge

They also found that the total force of reaction in the cutting of slices of soil by an L-shaped cutter is the sum of the forces of reaction on the blade and the stem,

$$R_n = R_1 + R_2 + R_3 + R_4$$

where,

R_n - total force of reaction

R_1 - force of reaction fue to cutting with the stem of the cutter

R_2 - force of reaction due to cutting with the blade of the cutter

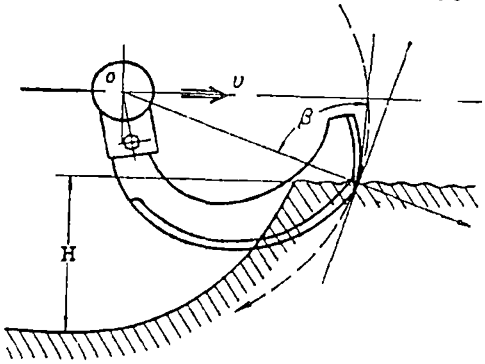
R_3 - force of reaction due to breaking of the slice of soil from the monolith

R_4 - force of friction due to the soil sliding over the surface of the working tool

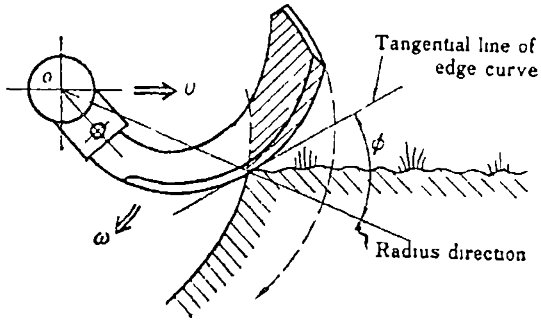
Sakai (1974) adopted the machine balancing theory of a free body analysis to the rotary power tiller. It was found that the rotary power tiller receives an upward resistance force of tillage from the soil through rotary knives, and in order to have a balanced travel, keeping a constant depth of tillage, the machine produces a downward force. The pressing down force consists of five groups and by knowing these, necessary weight of the rotary power tiller can be calculated by adjusting main diamensions and specifications during the term of planning the design. The machine performance of rotary tiller can be promoted by adopting the values from the theoretical calculations.

Sakai (1975) again analysed and explained three important factors for designing rotary knives with conceptional experiment data of rotary knives (Fig.8).

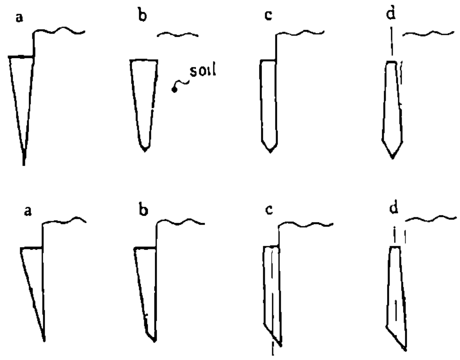
One of them is angle β which is the rake angle between the rotor radius direction and the tangential line of



(a) Rake angle



(b) Edge curve of the knife



(c) Section shape of the knife

Fig.8 Design factors for rotary knives (Sakai, 1975) tip-outside surface of the knife. β can be designed with values between 45 degrees and 80 degrees, which gives throwing action to the clods depending on soil and machine conditions.

The edge curve of the knife, had influence on the entwining of grass and straw around the blades and rotary axle and the tilling resistance. The angle $\emptyset$ between the radius direction and the tangential line to the edge curve is important to know its characteristics. Less entwining occurs when $\emptyset$ is more than 57 degrees and greater entwining occurs when $\emptyset$ is less than 57 degrees.

The third point was the sectional shape of the knife. This was related to the value of the frictional resistance between the knife and the untilled soil.

Because of high peak torques developed during each cut, it is important to stagger the blades in the different courses, with equal angular displacements between them, so that no two blades strike the soil at the same time. The stagger pattern should be approximately symmetrical about the longitudinal centre (Kepner et al., 1978). It was noticed that the useful soil force on a forward-rotating rotary tiller has an upward as well as a forward acting component. The relative magnitudes of these components were influenced by many factors including depth, rotor diameter, bite length, soil type and condition, type of blade and share clearance angle. The upward component reduces the amount of implement gravitational force that must be supported by the tractor wheels and the forward component results in a negative draft and negative specific energy requirement for traction.

According to Klenin et al. (1985) the positive drive which is employed in rotary tillers produces dynamic interaction between the tools and the soil and the plant roots therein. The bearing stresses become intense due to the concentration of great energy in a small volume and therefore such tools can be used to break hard lumps of soil, to process severely weed infested soils, sods and mineral soils and to cut stalks and plant shoots. The ability of the rotary tillers to loosen the soil increases as the thickness of the chip cut by each cutter is reduced. The maximum thickness of the chip equals the feed of one cutter. Since the cutter feed decreases with increasing values of kinamatic index which is the ratio of the linear velocity of the point under consideration to the velocity of the machine, the ability to loosen the soil improves. The following formula was developed to determine the value of kinamatic index.

$$\lambda = \frac{2\pi R}{S Z}$$

where,

λ - the kinamatic index

R - radius of the cutter drum

S - feed per cutter blade

Z - number of cutter units in single vertical plane

Bosoi *et al*. (1987) listed the following requirements for any rotary tiller. It should

(i) have high mobility to work on moist soils;

(ii) provide the possibility of changing the regime of soil cutting to prevent winding of plant residues and jamming of working tools with wet soil;

(iii) leave soil surface without furrows and swaths after tillage;

(iv) have high wear resistance, rigidity and a device to protect the working tools from damage when meeting obstacles.

The following formula was suggested to get the rotary tiller operating width,

$$B_g = \frac{N_{TP} - N_P}{(N_{\emptyset 1} + N_{01})\ (2 - \eta)} \qquad \frac{I_d}{Z_d}$$

where,

N_{TP} - tractor power

N_P - power consumed for the motion of the rotary tiller

$N_{\emptyset 1}$ - power consumed in the rotary tiller at $Z = 1$

N_{01} - power consumed in throwing the soil at $Z = 1$

Z_d - number of rotary tiller tynes mounted on one disc

I_d - distance between two discs

The diameter of the cutter drum, as given by them, was 2.5 to 3.5 times the depth of penetration of the blades. The frequency of rotation of the rotary tiller was given by

$$n = \frac{2\ V_P}{S\ Z_d}$$

where,

n - frequency of rotation

V_P - translational velocity of the unit

S - feed per cutter

Z_d - number of tynes mounted on one disc

Based on the above design criteria for the rotary tillers an attempt is made in this study to develop a new rotary tillage attachment to the already existing low cost garden tractor.

Materials and Methods

MATERIALS AND METHODS

The design details and selection of individual components of the rotary tiller and experimental methodology including economical analysis are presented in this chapter.

The funtional requirements of the rotary tiller are defined as follows:

a. The garden tractor with the rotary tillage attachment should be able to operate in the field at a forward speed equal to the pedestrian speed in the range of 1.5 to 2.5 km ph.

b. The total weight of the garden tractor and rotary tillage attachment should not be more than 175 kg so that it can be lifted by two persons for transportation and can easily be balanced during operation.

c. The implement should be able to cover a width not less than 30 cm and it should penetrate to a depth of 10 to 15 cm.

d. The total cost of garden tractor along with rotary tillage attachment should be around Rs.22,000/- so that an average farmer can afford to own it.

e. The position of the controls and the vibration and sound levels should be within the allowable ergonomic limits.

f. All the standard components should easily be available from local markets and other components can be fabricated with readily available materials and technology.

g. After tillage the surface of the soil should be left without ridges and furrows.

h. The parts of the rotary tiller must have high resistance to wear and high strength to prevent the breakage of the working tools when they hit hard obstructions.

i. There should be a protective cover to the rotating blades to protect the operator from flying stones and clods and to prevent accidents during operation.

3.1 General layout of the machine

In order to achieve these functional requirements, a rotary tiller was designed. The main components of the rotary tiller are mainframe, power transmission elements, blade-assembly, hitching mechanism and protective cover.

3.1.1 Mainframe

The mainframe which is attached to the garden tractor through hitching mechanisms, holds the blade assembly, power transmission elements and the protective cover. The mainframe must be as light as possible to reduce the cost and total weight of the machine but yet strong enough to take load and withstand the shocks during field operation. It should be rigid enough to hold all the parts in correct alignment.

The loads coming on the mainframe are mainly the force due to the transmission of torque to the rotor shaft, the lifting force of the rotary tiller and the pressing forward force of the rotary tiller. The effect of these forces are to constitute a bending moment on the mainframe at the rear hitch point. These forces were separately analysed and the cross-section of the mainframe at the rear hitch point was determined.

The axial force due to the transmission of torque to the rotor shaft 'T_f' is given by

$$T_f = \frac{5.4 \times 4500 \times 1000 \times 2}{2 \times \pi \times 290 \times 61} = 437.25 \text{ kgf}$$

The lifting force, as specified by Sakai (1974), of the rotary tiller 'L_f' is given by

$$L_f = \frac{71620\, \theta_1\, P_e\, \eta t}{N_r\, (R - ih)}$$

where,

L_f - lifting force kgf

θ_1 - coefficient of lifting force (0.7)

P_e - engine horse power

η_t - transmission efficiency from the engine to the rotary shaft (0.8)

N_r - speed of the rotary shaft, rpm

R - radius of the rotary knives, cm

h - maximum depth of tillage, cm

i - location coefficient of the centre of rotary tilling resistance (0.1-0.05 of h)

$$\therefore \quad L_f = \frac{71620 \times 0.7 \times 5.4 \times 0.8}{290 \times (21.5 - 0.1 \times 15)} = 37.78 \text{ kgf}$$

Pressing forward force of the rotary tiller 'P_f' is given by

$$P_f = \frac{71620\ \sigma_2\ P_e\ \eta_t}{N_r\ (R - ih)}$$

where,

σ_2 - coefficient of pressing forward force (0.7 to 1.2)

$$\therefore \quad P_f = \frac{71620 \times 0.7 \times 5.4 \times 0.8}{290 \times (21.5 - 0.1 \times 15} = 37.78 \text{ kgf}$$

The resultant 'R_f' of the lifting force 'L_f' and the pressing forward force 'P_f' acts at an angle of 45 degrees with the horizontal. The magnitude of 'R_f' is given by

$$R_f = (L_f^2 + P_f^2)^{1/2}$$

$$= (37.78^2 + 37.78^2)^{1/2} = 53.42 \text{ kgf}$$

The component of this resultant force (F_f) in the direction parallel to the axis of the mainframe 'R_f' is given by

$$R_f' = R_f \cos 4 = 53.28 \text{ kgf}$$

Total load on the mainframe = 437.25 + 53.28

= 490.53 kgf

$\therefore$ Load on either side $= \frac{490.53}{2} = 245.25$ kgf

Bending moment at the rear hitch point 'M' is given by

M = 245.25 x 40 = 9810.00 kg mm

The cross section of a rectangular mild steel flat is found out from

$$M = \frac{bd^2}{6} \times fs$$

where,

b - breadth of the section

d - depth of the section

fs - permissible bending stress

$$bd^2 = \frac{9810 \times 6}{12} = 4905$$

A breadth equal to 50 mm was selected in order to accommodate the idle shaft and rotor shaft in the mainframe.

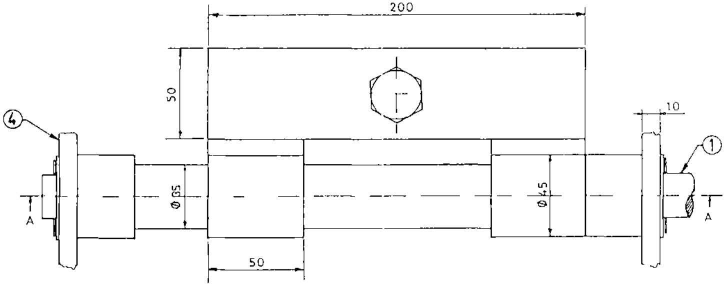
$$d = \left(\frac{4905}{50}\right)^{1/2} = 9.9 \text{ mm} = 10 \text{ mm}$$

Hence the mild steel flat of 50 x 10 mm cross section was selected for the mainframe.

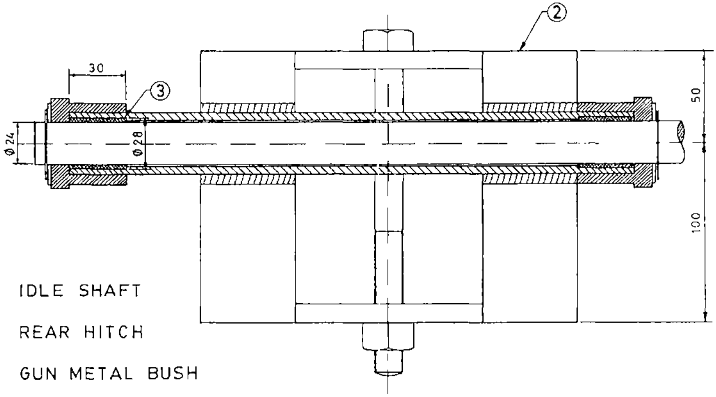
3.1.2 Design of power transmission elements

For transmitting the power of the engine from the intermediate shaft of the garden tractor to the rotor shaft, chain and sprocket transmission have been chosen, as these are standard components readily available and moreover it is easy for repair and maintenance. In order to change the depth of penetration and to facilitate transportation while the rotor is out of work, there should be a provision for raising and lowering the blade assembly without changing the distance between the rotor shaft and the rear hitch point. As the position of the blade assembly changes the centre distance between the intermediate shaft and the rotor shaft changes. The easiest way, for achieving this requirement is to bring the power from the intermediate shaft to the rear hitch point from where it can be taken to the rotor shaft. To serve this purpose an idle shaft which can revolve inside the rear hitch centre was designed. The details of the idle shaft and rear hitch are shown in Fig.9.

The intermediate shaft of the garden tractor is having a speed of 160 rpm when the engine is running at its rated speed of 1800 rpm. Correspondingly a speed of 290 rpm is required for the rotor shaft (refer 3.1.2). Chain and sprocket transmission system was so designed to get the increase in speed to the idle shaft. The speed of both the idle shaft and rotor shaft are kept at 290 rpm.



PLAN



1 IDLE SHAFT
2 REAR HITCH
3 GUN METAL BUSH
4 MAIN FRAME

SECTIONAL ELEVATION A-A

Scale - 1 2 3

All dimensions in mm

Fig 9 REAR HITCH & IDLE SHAFT ASSEMBLY

The first stage chain and sprocket transmission is designed with 12.7 mm pitch 27 teeth sprocket wheel and 15 teeth sprocket penion. The centre distance between the intermediate shaft of the garden tractor and the idle shaft is 490 mm. The detailed design procedure is given in the Appendix I. The specifications of the selected ISO/DIN 084-1 R 1248 H chain is given in Appendix II and the teeth specifications is given in Appendix III.

The second stage chain and sprocket transmission was designed with two 15 teeth sprockets of 12.7 mm pitch to get a transmission ratio of unity. The centre distance between the idle shaft and the rotor shaft is 400 mm. The detailed design is given in Appendix IV.

3.1.2.1 Design of intermediate shaft

For designing the intermediate shaft it was considered that the entire engine power is transmitted to the idle shaft and the diameter so obtained was compared with the diameter of the shaft which is already existing in the garden tractor. The various loads acting on the shaft which were considered for the design are shown in Fig.10. The load at point C due to chain drive acting at 84 degrees to horizontal,

$$Q_{oc} = \frac{1.15 \times 4500 \times 5.4 \times 1000}{\pi \times 160 \times 182}$$

$$= 305.46 \text{ kgf}$$

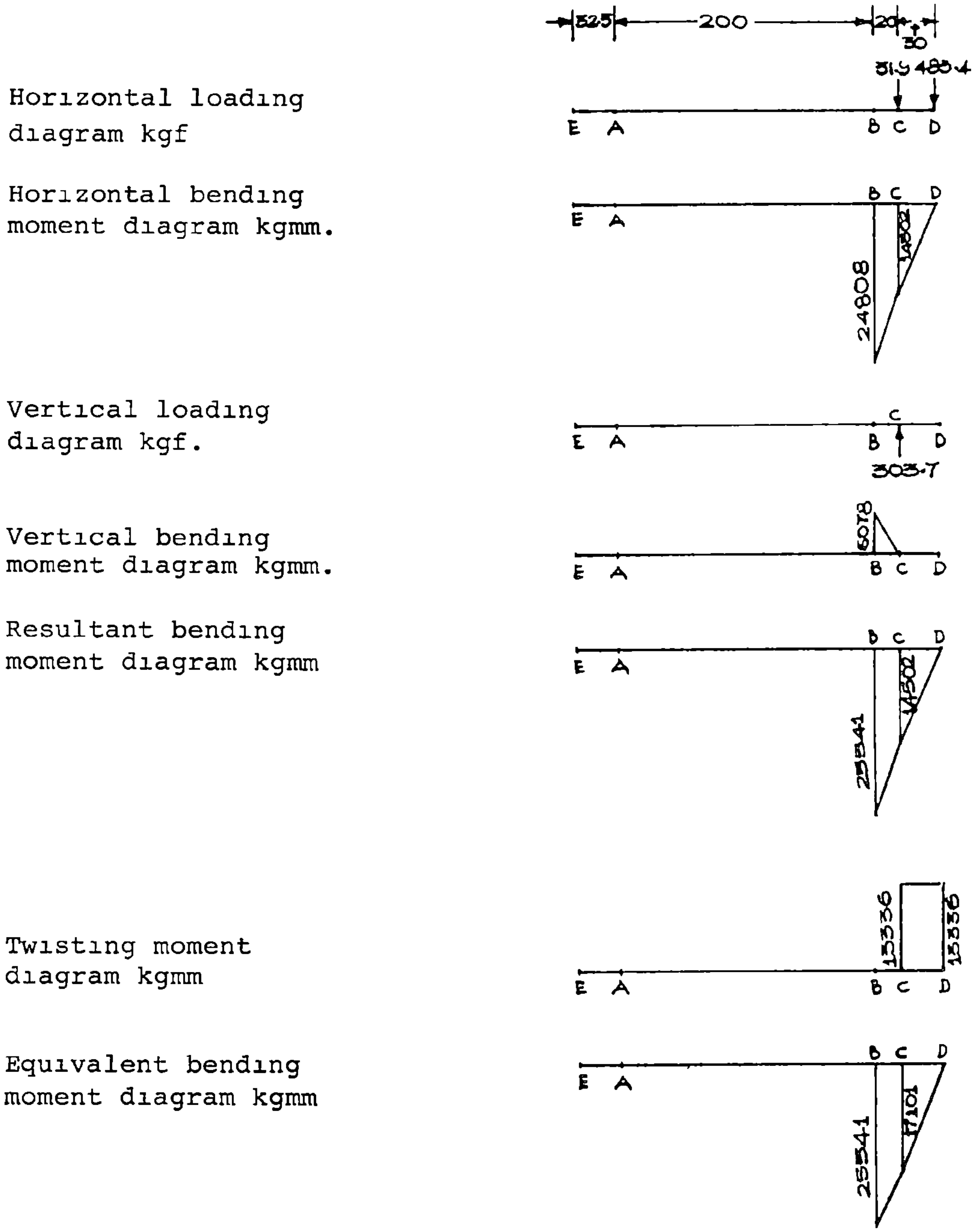


Fig. 10 FORCE AND BENDING MOMENT DISTRIBUTION ON INTERMEDIATE SHAFT

The load at point D due to chain drive in the horizontal direction,

$$Q_{od} = \frac{4500 \times 5.4 \times 1000}{\pi \times 160 \times 100}$$

$$= 483.4 \text{ kgf}$$

The calculated values of horizontal force, horizontal bending moment, vertical force, vertical bending moment, resultant bending moment, twisting moment and equivalent bending moment acting on the intermediate shaft are shown in Fig.10.

Gun metal bushes were fixed at point A and B and the driving sprocket was fixed at point C. The sprocket penion driving the ground wheels was fixed at point E and the 25 teeth sprocket wheel which drives the idle shaft was fixed at D.

3.1.2.1.1 Selection of shaft diameter

For axle steel, minimum diameter at point B, where the equivalent bending moment is maximum is,

$$= \left(\frac{32 \times 25541}{\pi \times 25.0}\right)^{1/3}$$

$$= 21.83 \text{ mm}$$

Hence a diameter of 22 mm, which is already present with the garden tractor was selected.

In order to accommodate another sprocket to power the rotary tiller from the intermediate shaft, the length of the existing shaft was increaed by 50 mm.

3.1.2.2 Design of idle shaft

The various loads acting on the idle shaft are shown in Fig.11. The load acting at point C due to chain drive in the horizontal direction is,

$$Q_{oc} = \frac{4500 \times 5.4 \times 1000}{\pi \times 290 \times 61}$$

$$= 437.25 \text{ kgf}$$

Load acting at point D due to chain drive acting at 41 degrees to horizontal is,

$$Q_{od} = \frac{4500 \times 5.4 \times 1000}{\pi \times 290 \times 61}$$

$$= 437.25 \text{ kgf}$$

The calculated values of horizontal forces, horizontal bending moment, vertical forces, vertical bending moment resultant bending moment, twisting moment and equivalent bending moment acting on the idle shaft are shown in Fig.11.

Gun metal bushes were fixed at points A and B. The sprocket fixed at point C delivers power to the idle shaft and the power is taken out from the idle shaft through the sprocket fixed at point D.

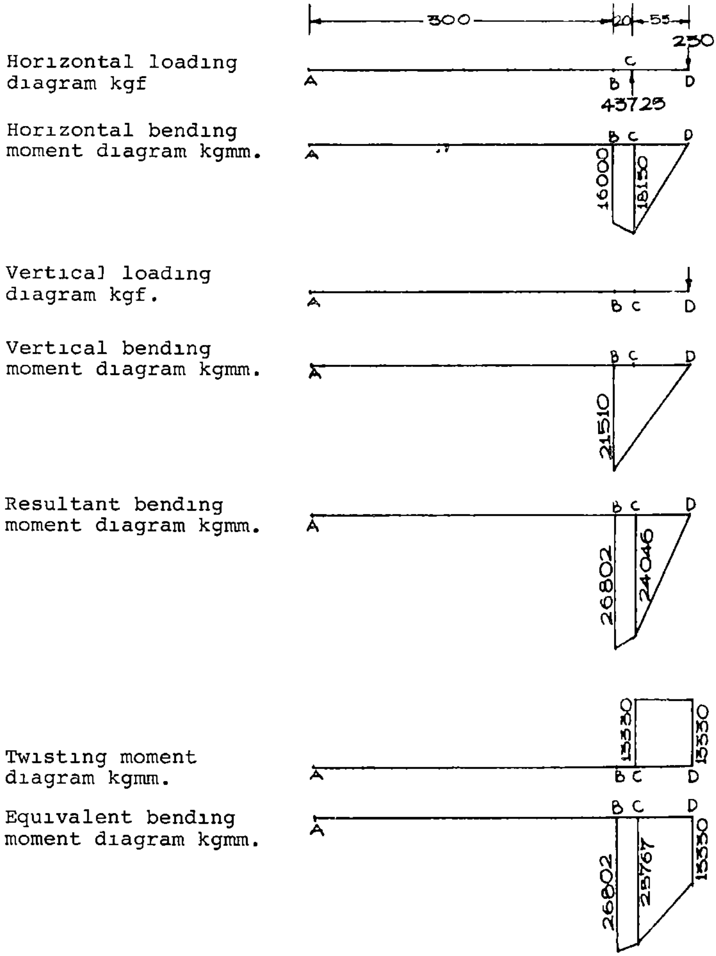


Fig 11 FORCE AND BENDING MOMENT DISTRIBUTION ON IDLE SHAFT

3.1.2.2.1 Selection of shaft diameter

The critical section of the shaft is at B, where the equivalanet bending moment is maximum. For axle steel, minimum diameter required at point B is

$$d = \left(\frac{32 \times 26802}{\pi \times 25.0} \right)^{1/3}$$

$$= 22.18 \text{ mm}$$

Hence a diameter of 24 mm is selected.

The details of the power transmission system are shown in Plates I & II.

3.1.3 Blade assembly

The blade assembly is held by the mainframe at two points and lateral drive is given to the rotor shaft. The lateral drive i.e., the drive through one side of the shaft, allows arrangement of the tynes over the whole length of the shredding drum at equal distances, providing continuous tillage. The main parameters of the rotor unit were selected by using a nomograph (Appendix V) which is a graphical representation of the correlation between the parameters and the working regimes of rototillers.

The feed per cutting blade(s) was fixed as 20 cm which is within the permissible limits for secondary tillage.

Standard cutting blades were selected, which when fitted to the rotor shaft makes a cutter drum diameter of 43.00 cm (Fig.12). Therefore the radius of the circle described by the cutter edge 'R' during rotation is 21.50 cm The maximum forward speed of the garden tractor in the field (V_t) is 3.5 kmph or 0.97 m per sec. From these three parameters the required speed of the rotor (n) is found to be 290 rpm. The circumferential speed of the cutter edge (V_r) and the ratio of rotary and translatory velocities of motion (λ) are found to be 6.50 m per sec and 6.8 respectively.

Specific resistance to rotary tilling depends on the soil state, the cutting velocity, the shape of the rotary tilling tyne and other factors which are not governed by strict mathematic relations. For design calculations a safe value of 0.50 kg/cm^2 was taken as specific resistance to rotary tilling for secondary tillage of most soils. It was also assumed that 75 per cent of the engine power is used for rotary tilling and the transmission efficiency is 85 per cent. Therefore power available at the rotor shaft is only 3.5 hp. The maximum possible width of the rotary tiller (W) was worked out on the basis of these values.

$$W = \frac{3.5 \times 75}{0.5 \times 15 \times 0.97}$$

$$= 36 \text{ cm}$$

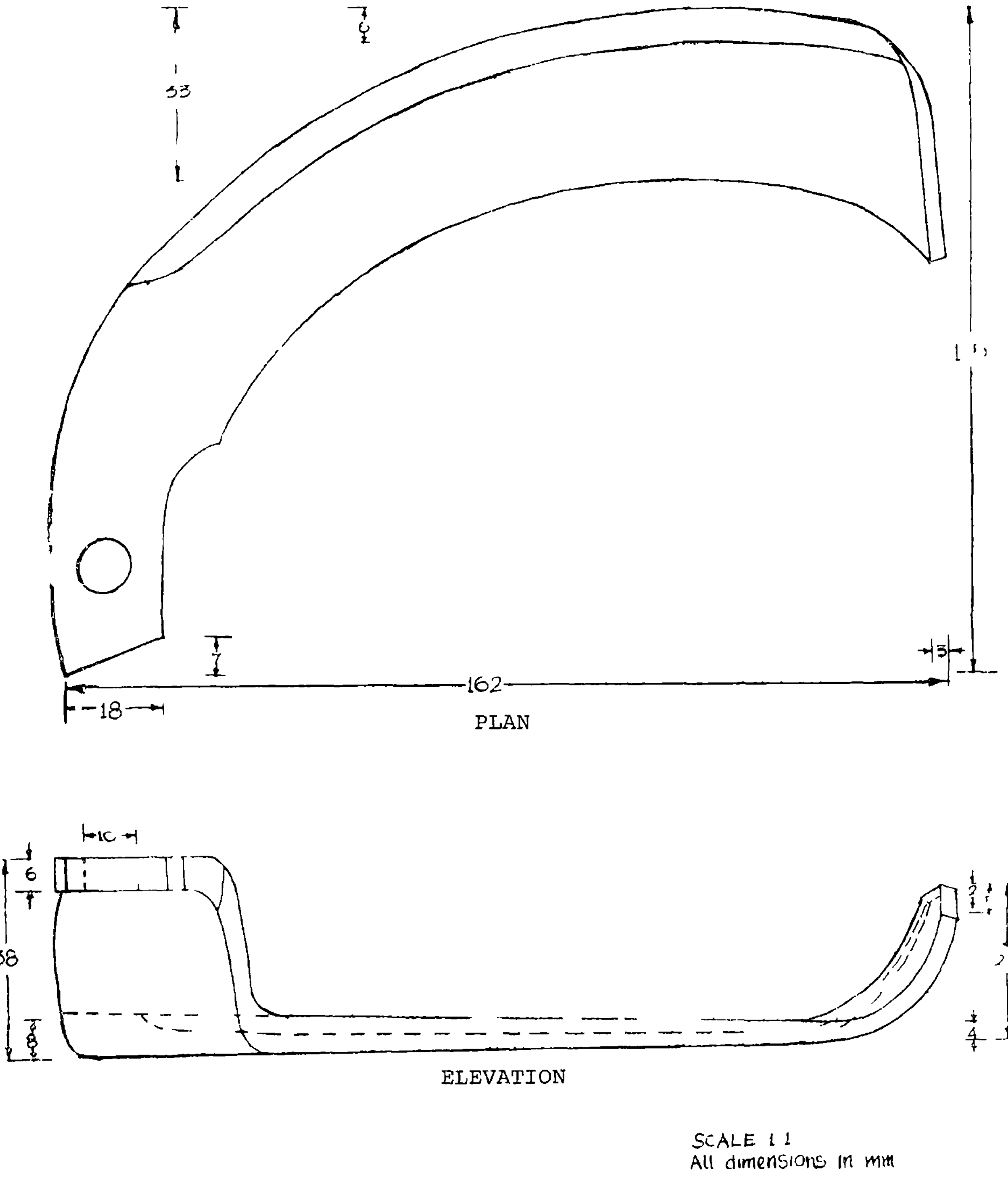


Fig.12 BLADE OF THE ROTARY TILLER

In order to cover this width, twelve tynes, each having a working width of 3 cm was selected. The arrangement of these blades on the rotor shaft is shown in Plate I.

3.1.3.1 Design of cutter drum shaft

The shaft of the cutter drum is the maximum loaded element of the rotary tiller Tubular drum shafts are capable of transmitting large torque in spite of their smaller weight and are better adapted to torsional vibrations. The dimensions of the tubular shaft was determined on the basis of the maximum torque to be transmitted. Stresses are determined in the cross section of the pipe at the bore near the face end of the shaft where the moment of resistance is minimum. Torsional stresses are given by the formula;

$$fs = \frac{Mt}{W}$$

where,

Mt - turning moment on the shaft

$$W = \frac{\pi D^2 \delta}{2} = 1.57 D^2 \delta$$

D - outer diameter of the shaft

δ - thickness of wall of the tube

The value of maximum turning moment on the shaft is calculated as follows:

$$M_t = \frac{5.4 \times 4500}{2 \pi \times 288} = 1342 \text{ kg cm}$$

The outer and inner diameters of the mild steel shaft taken were 5 and 4 cm respectively. A factor of safety of 4 was given to take bending stresses and additional torsional stresses into account. The value of the induced shear stress is

$$fs = \frac{1342 \times 4}{1.57 \times 5^2 \times 0.5} = 273.5 \text{ kg/cm}^2$$

The design is safe for mild steel shaft.

3.1.4 Hitching mechanism

The mainframe is held to the chasis of the garden tractor through two hitch points. The hitching mechanism holds the mainframe firmly to the chasis and enables the blade assembly to work as a fully mounted unit of the garden tractor. There is a provision to lower the tyne assembly when deep tilling (upto 15 cm) is required. This is achieved by raising the front side of the mainframe. The constructional details of the hitching mechanism are shown in Plate I & II.

3.1.5 Protective shield

The soil is extensively broken up and is thrown to considerable distance during the operation of rotary cultivators. A protective cover to the rotating blades is found necessary in order to protect the operator from flying stones and clods. This is also necessary for preventing the

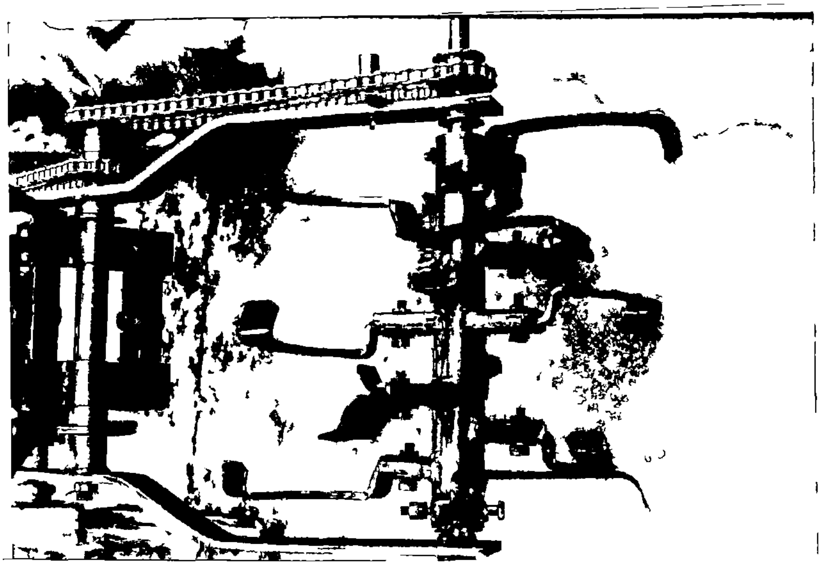


Plate I Blade assembly, power transmission and rear hitch

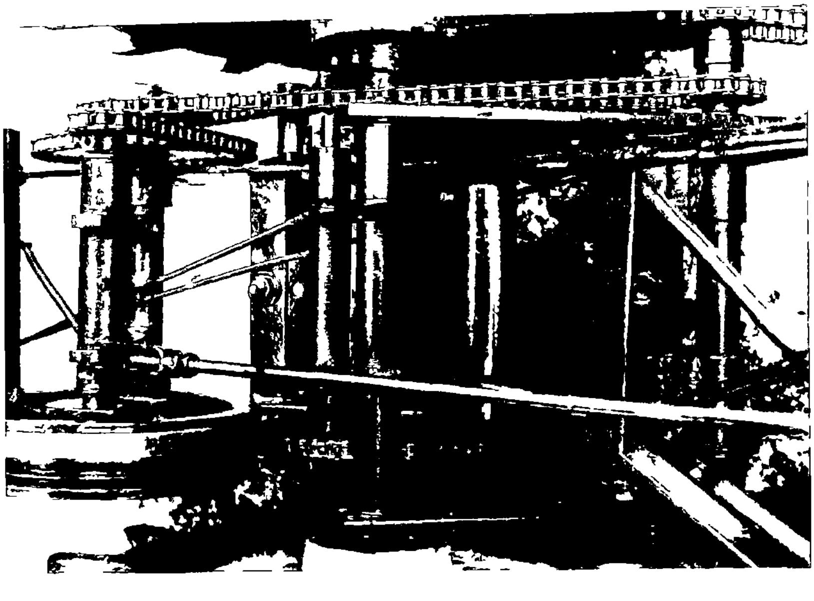


Plate II Hitching mechanism and power transmission soil from being thrown over the crop and to protect the crops from entwining in the rotary blades. The slice cut out by the blades are pulverised against the shield and other blades. The type of tilth produced is dependant on the position of the shield.

The protective shield was fabricated with 20 gauge galvanised iron sheet and 18 x 5 mm mild steel flats and was bolted to the mainframe above the blade assembly. A rubber flap was provided at the rear side of the protective shield.

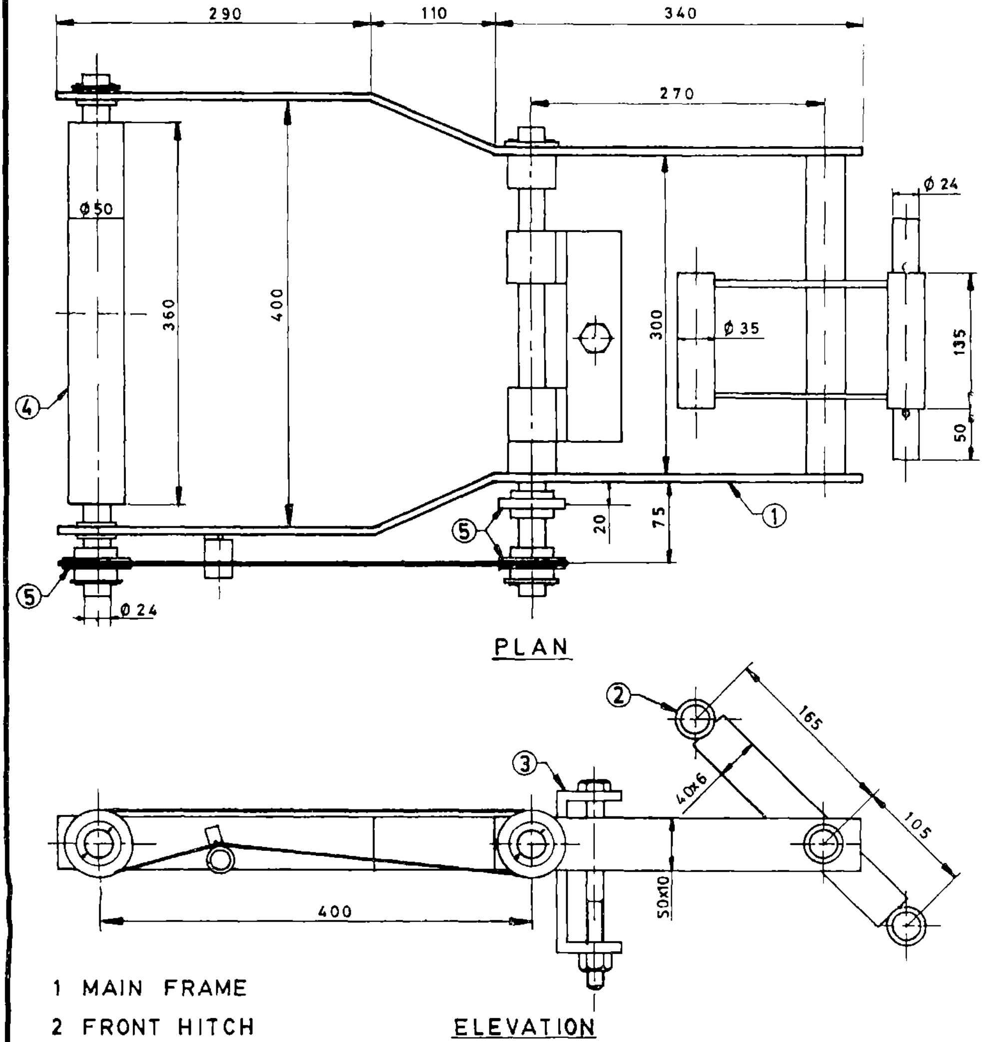
3.1.6 Assembling details

The individual machine elements, after fabrication were assembled to form the rotary tillage attachment of the garden tractor. The dimensions and relative position of individual elements in the machine is shown in the assembly drawing (Fig.13).

The rotary tillage attachment was then connected to the garden tractor (Fig.14). The garden tractor with rotary tillage attachment is shown in Plate III.

.2 Experimental programme

After assembling the rotary tillage attachment to the garden tractor, it was put in operation in the laboratory, keeping the ground wheels and blade assembly lifted from the

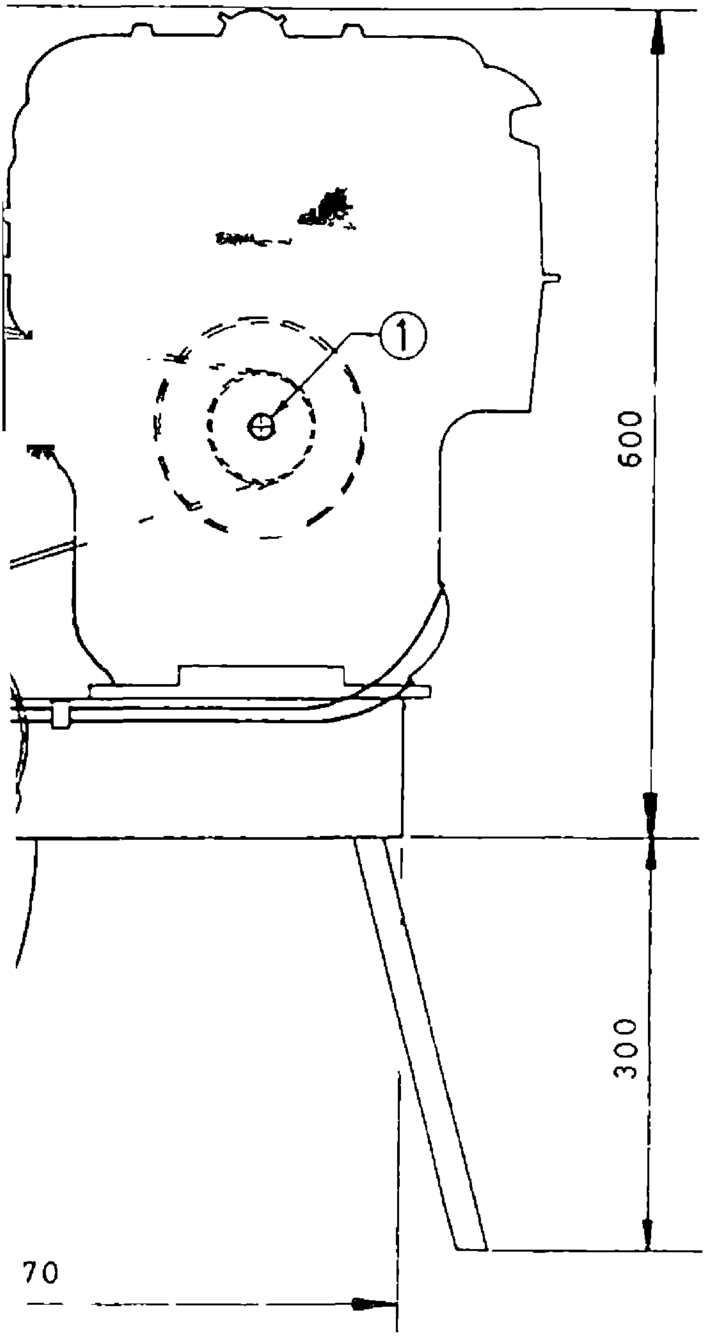


1 MAIN FRAME
2 FRONT HITCH
3 REAR HITCH
4 ROTOR DRUM SHAFT
5 SPROCKET 15teeth

Scale - 1 5
All dimensions in mm

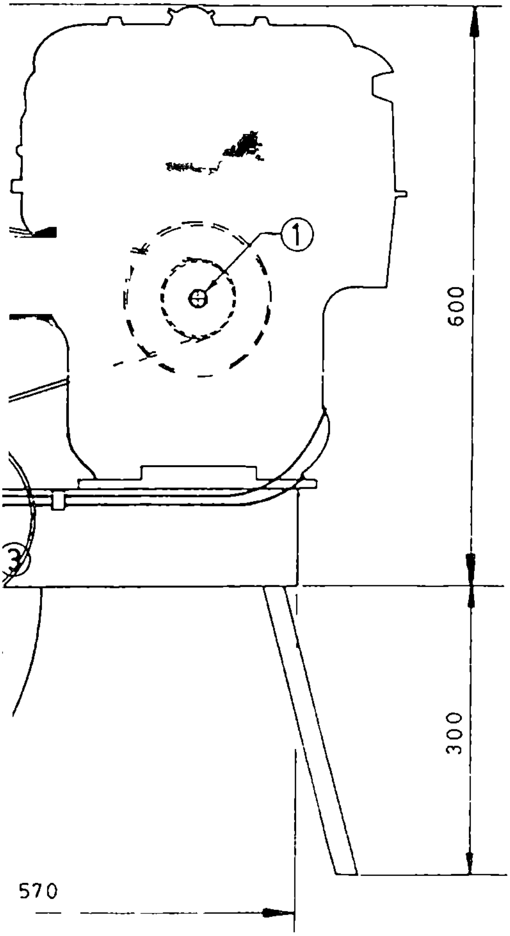
Fig 13 MAIN ASSEMBLY OF ROTARY TILLAGE ATTACHMENT

7 MAIN FRAME
8 REAR HITCH
FT 9 FRONT HITCH
.XLE 10 PROTECTIVE COVER
11 BLADES



ACHMENT

	7	MAIN FRAME
	8	REAR HITCH
AFT	9	FRONT HITCH
AXLE	10	PROTECTIVE COVER
	11	BLADES



TACHMENT

ground for about three hours. The alignments of the chains and other rotating [illegible] were found to be correct.

Then the machine was operated in the field for about four hours with different operating speeds. The machine was found satisfying its basic [illegible]ments.

Various tests were [illegible]ted in the laboratory and in the field to evaluate the [illegible] of the rotary tillage attachment to the KAU garden tractor.

3.2.1 Laboratory tests

3.2.1.1 Weight of the implement

The weight of the implement and the total weight of the implement along with the garden tractor were determined using a platform type weighing balance.

3.2.1.2 Speed of the cutter

The speed of the cutter was found in relation to the speed of the engine. The speed of the cutter shaft at different engine speeds were measured by using a non-contact digital type tachometer. This was done with ground wheels lifted from ground.

3.2.1.3 Location of the centre of gravity

The centre of gravity of the garden tractor along with the rotary tillage attachment was determined in the vertical plane which laterally bisects the machine, using a platform balance. The total weight of the garden tractor and the rotary tiller was first determined. Then the reactions at the front side of the garden tractor when the chasis is in the horizontal position and in an inclined position were determined. From these observations the location of the centre of gravity was found out.

3.2.2 Field tests

Before conducting the tests, the field was given a primary tillage using a tractor drawn mould board plough. The moisture content and bulk density of the field were found out on dry basis. After conducting the tests, to get a measure of tilth produced by the machine, the bulk density of the tilled field was again found out.

Experimental set up for the measurement of sound level, engine speed and forward speed are shown in Plate IV.

3.2.2.1 Field capacity

A plot of known size was selected and time taken to plough the area was noted. The field capacity was found which

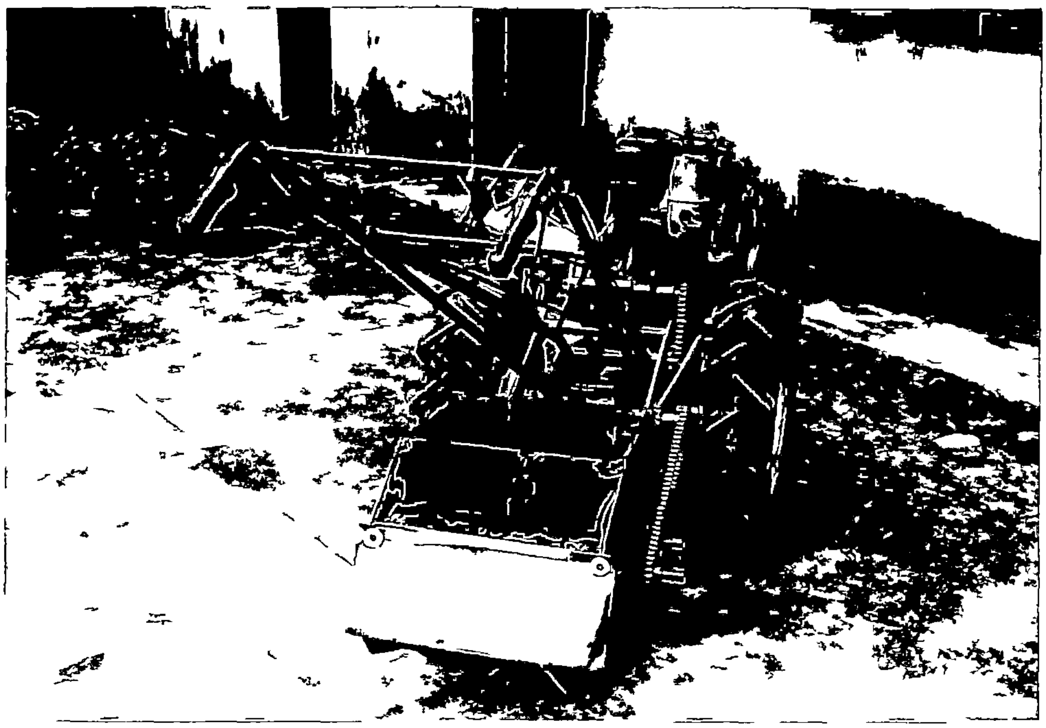


Plate III Garden tractor with rotary tillage attachment

Plate IV Measurement of sound level, engine speed and forward speed is the average rate of coverage including time lost in turning at head lands, slopping of the engine due to overloading removing the weeds clinged on the tynes etc.

3.2.2.2 Fuel consumption

The fuel tank was completely filled before the starting of the fuel consumption test. The garden tractor with rotary tiller was then operated in an area of known size. Again the fuel tank was filled after the completion of the field operation. The quantity of fuel required to completely fill the tank was noted. The fuel consumption for operating the rotary tiller per ha and per hr has been found.

3.2.2.3 Sound level

Using sound level meter, the intensity of sound at various engine speeds, when operating the rotary tiller in the field was measured.

3.2.2.4 Visual observations

Ease of operation and adjustments in the field were also evaluated by observation.

3.2.2.5 Comparison with other implements

The tilth produced by the garden tractor with rotary tillage attachment was compared with the tilth produced by tractor drawn spring loaded cultivator and Kubota power tiller with rotavator. This was done by studying the change in bulk density of the field after the use of these machines.

3.3 Economic analysis

It was assumed that the garden tractor is used for 150 hours in a year for operations other than rotary tillage. If a rotary tiller to attach with the garden tractor is available, it would increase the total annual use of the garden tractor. Any increase in total annual use will reduce the unit cost of operation. The relation between unit cost of operation and total annual use of garden tractor was found out.

The cost of ploughing per hectare at different total annual use (hectares per year) was found out and it was compared with the hiring rates of Kubota power tiller to find the break even hectarage, i.e., the size of holding which will justify the ownership of a garden tractor.

Results and Discussion

RESULTS AND DISCUSSION

The results of the laboratory and field studies conducted and economics of operation are presented and discussed in this chapter.

4.1 Laboratory tests

4.1.1 Weight of the implement

Weight of the implement was found to be 30.50 kg. Total weight of the implement and garden tractor is 175.50 kg.

4.1.2 Speed of the cutter

Speed of the cutter in relation to engine speed was determined for five different speeds of the engine with the ground wheels raised from ground. The values obtained are given in Table 3.

Table 3. Relationship between speeds of engine and the cutter shaft

Sl. No.	Engine speed (rpm)	Cutter shaft speed (rpm)
1	810	128
2	895	142
3	1295	204
4	1430	225
5	1625	256

4.1.3 Location of centre of gravity

The reactions at the front side of the chasis at two different positions were determined. The vertical reaction at the front side of the chasis when it is lowered to the ground level is 37.0 kgf. When the chasis is horizontal this reaction is 6.8 kgf. From these values, the centre of gravity of the garden tractor along with rotary tillage attachment is located diagramatically (Fig.15).

The centre of gravity of the garden tractor along with rotary tillage attachment was found to be located at a distance of 22.00 mm in front of the ground wheel axle and 450 mm above the ground level.

The movement of the centre of gravity close to the ground wheel axle had improved the stability of the complete unit, compared to the garden tractor alone. The garden tractor along with the rotary tillage attachment was found to be stable during field operation and in turning.

4.2 Field tests

Field tests on the garden tractor has been carried out at the KCAET Farm, Tavanur for evaluating the field performance of the machine. A nearly level field was selected and was given a primary tillage with a tractor drawn mould board plough. The soil moisture content on dry basis was 16 per cent. The bulk density on dry basis at various places were determined using a core sampler and the average value was found to be 1.56 gm per cc. After conducting the tests, to get a measure of tilth produced by the machine, the bulk density of the tilled field was again determined. After conducting the tests the average value of bulk density in the tilled field was estimated to be 1.37 gm per cc.

The depth of tillage was found to vary from 10 to 15 cm.

4.2.1 Field capacity

The theoretical field capacity of the machine at a forward speed of 2.50 kmph is 0.09 ha per hr. The effective field capacity at four different throttle positions were found out and corresponding field efficiencies were calculated. The area covered and the time taken for each trial is shown in Table 4. The actual operating speeds at the first, second, third and fourth trials were 1.54 kmph, 1.80 kmph, 2.00 kmph and 2.70 kmph.

The width covered by the implement was only 30 to 32 cm instead of the actual width of the implement. The field efficiency of the machine was found to be increasing with increase in engine speed as well as the operating speed. The maximum value of field efficiency observed was 74.6 per cent which corresponds to a forward speed of 2.70 kmph. However at

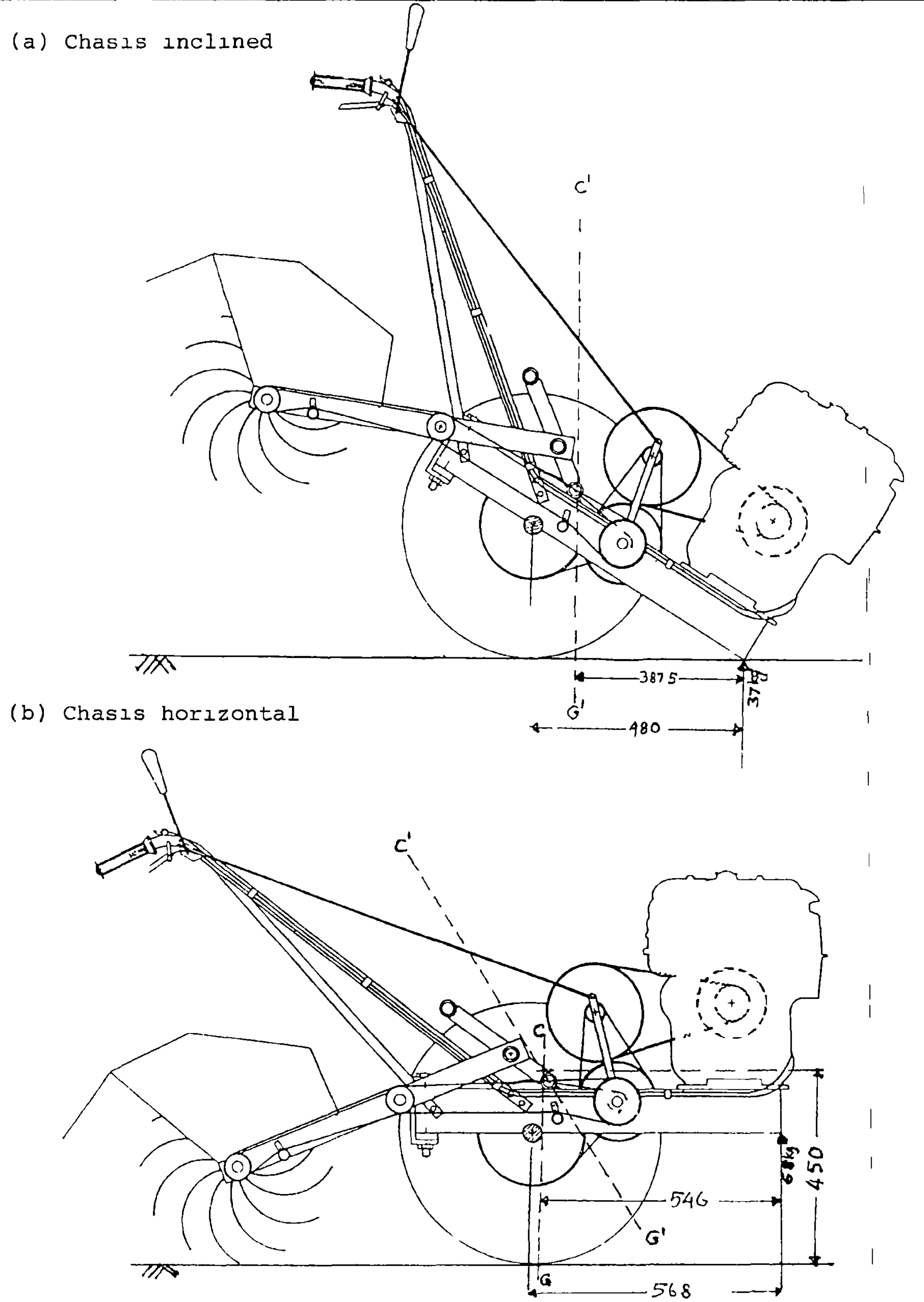


Fig.15 CENTRE OF GRAVITY OF GARDEN TRACTOR

Table 4. Effective field capacity and field efficiency

Trial No.	Area covered			Total time spent (min)	Effective field capacity (ha per hr)	Field efficiency (per cent)
	Length (m)	Width (m)	Area (ha)			
1	20	10	0.02	30.61	0.039	43.5
2	20	10	0.02	26.32	0.045	50.4
3	20	10	0.02	22.04	0.054	60.5
4	20	10	0.02	17.88	0.067	74.6

this high speed, the manoeuvrability of the machine was found difficult in the field due to high walking speed and increased vibration.

4.2.2 Fuel consumption

The quantity of diesel fuel required for ploughing 4 different plots of size 20 x 10 m at 4 different speeds were noted. Table 5 shows the quantities of fuel consumed in the field and the estimated values of fuel consumption in litres per hectare and in litres per hour at 4 different trials.

From the table it is seen that the fuel consumption per hectare is more even at low operating speeds because the total time taken to cover one hectare is more. The fuel consumption per ha decreases as the speed of operation increases. The fuel consumption per hour is less at low operating speeds and it increases as the speed of operation is increased.

Table 5. Fuel consumption at different speeds

Trial No.	Area covered (ha)	Forward speed (kmph)	Total time spent (min)	Fuel required (l)	Fuel consumption l per ha	l per hr
1	0.02	1.54	30.61	0.343	17.14	0.672
2	0.02	1.80	26.32	0.332	16.63	0.754
3	0.02	2.00	22.04	0.316	15.81	0.861
4	0.02	2.70	17.88	0.300	15.00	1.000

4.2.3 Sound level

Sound levels at various operating speeds were measured in the field and are given in Table 6.

Table 6. Sound level at different speeds

Sl.No.	Operating speed (kmph)	Sound level d B(A)
1	1.50	84
2	1.70	86
3	1.82	87
4	1.94	89
5	2.10	92
6	2.30	97

The acceptable level of sound for a duration of 8 hours per day is 90 d B(A) (Liljedahl _et al_., 1984). Hence it can be concluded that the machine can be operated at a field speed of upto 2 kmph keeping the sound level within permissible limits.

4.2.4 Visual observations

Operator can easily walk behind the rotary tiller taking the advantage of the offset handle and can easily turn the garden tractor. During field operation turning of the garden tractor towards left is easier than turning towards right. Steering is easy at field speeds less than 2.5 kmph. At higher speeds steering become difficult.

During field operation, if the engine slows down considerably due to momentary overloads, the rotary tiller needs to be lifted slightly in order to prevent the stalling of the engine.

Transportation of the garden tractor down the steep slopes, without disengaging the rotary tiller is found comparatively difficult.

4.2.5 Comparison with other implements

The tilth produced by the rotary tillage attachment of the garden tractor was compared with three different treatments, viz.,

1. One operation of tractor drawn spring loaded cultivator
2. Two operations of tractor drawn spring loaded cultivator
3. One operation of Kubota power tiller with rotavator

The initial bulk density of the field was 1.56 gm per cc. The change in bulk density after each of these treatments are given in Table 7.

Table 7. Bulk density of soil after different treatments

Sl.No.	Treatment	Bulk density gm per cc
1	One operation of tractor drawn spring loaded cultivator	1.48
2	To operations of tractor drawn spring loaded cultivator	1.36
3	One operation of Kubota power tiller with rotavator	1.35
4	One operation of garden tractor with rotary tillage attachment	1.37

From the table it is clear that the tilth produced by one operation of the garden tractor with rotary tillage attachment is comparable with that of two operations of tractor drawn spring loaded cultivator and one operation of Kubota power tiller with rotavator.

The evenness of the tilled field was more in the case of Kubota power tiller, followed by garden tractor and tractor drawn cultivator.

4.3 Economic analysis

The cost of production of the rotary tillage attachment is estimated to be Rs.1500.00. However, the total cost of the garden tractor along with rotary tillage attachment was found to be Rs.22,000.00.

4.3.1 Cost of operation

4.3.1.1 Fixed costs

The main items of the fixed cost are depreciation and interest on investment. It was assumed that the life of the garden tractor is 10 years. The annual depreciation D is given by

$$D = \frac{0.9\ C}{L}$$

where,

C   original cost, rupees

L - service life, years

$$\frac{0.9 \times 22000}{10} = \text{Rs.}1980.00 \text{ per year}$$

The annual interest 'I' of the initial investment is given by

$$I - 0.55\ C \times i$$

where,

i - rate of interest

$$I = 0.55 \times 2200 \times \frac{12}{100}$$

= 1452.00 per year

The total fixed cost = 1980 + 1452

= 3432.00 per year

4.3.1.2 Operating costs

The main items are of the operating cost are listed below.

a. Fuel charges : Fuel consumption in the field at an operating speed of 2 kmph is 0.85 l per hr. Cost of one litre of diesel is Rs.6.00.

Hence fuel charges per hr = 0.85 x 6

= Rs.5.10

b. Lubrication charges per hr @ 10% fuel cost

$$= 5.10 \times \frac{10}{100}$$

= Rs.0.51

c. Labour charges per hr = Rs.3.75

d. Repair maintenance charges per hr

= Rs.0.75

Total operating cost per hr = 5.10 + 0.51 + 3.75 + 0.75

= Rs.10.11

4.3.2 Unit cost of operation and total annual use

The unit cost of operation is given by the relationship

$$Cu = (Cf/x) + Co$$

where,

Cu - unit cost of operation

Cf - total annual fixed cost

x - annual use in number of units (time or area)

Co - operating cost per unit

It was found that the unit cost of operation of the garden tractor decreases with increase in total annual use (Fig.16).

It was assumed that the garden tractor is used for 200 hours in a year for operations other than rotary tillage. A rotary tillage attachment would help in increasing the annual use and thereby reduce the unit cost of operation.

4.3.3 Cost of operation per hectare and size of holding

The average field capacity of the garden tractor with rotary tillage attachment is 0.054 ha per hr. Hence it will take 18.5 hours to cover one hectare. The operating cost for one hectare is Rs.187.00. The total cost of ploughing one hectare 'Cu' is given by

$$Cu = \frac{3432 \times 18.5}{200 + 18.5\,a} + 187.00$$

where,

a - total area ploughed (ha)

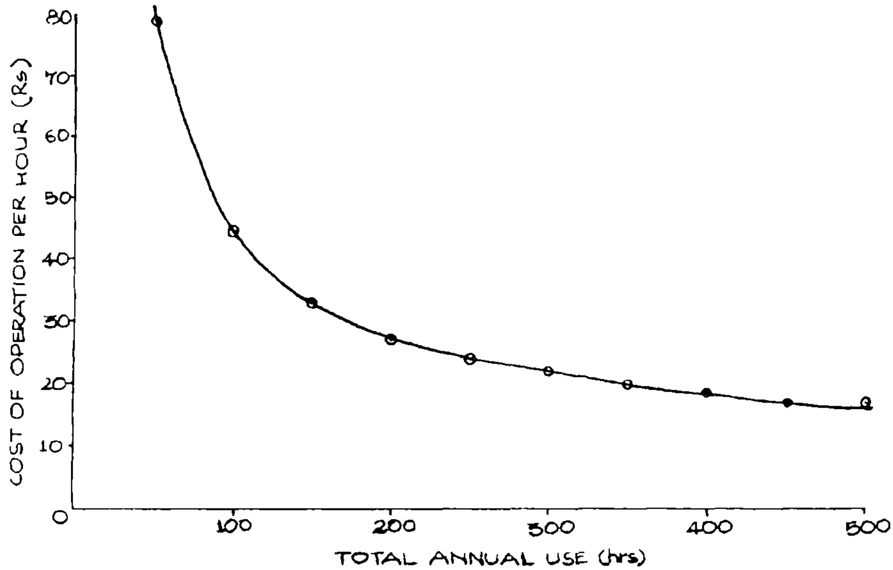


Fig 16 COST OF OPERATION Vs TOTAL ANNUAL USE

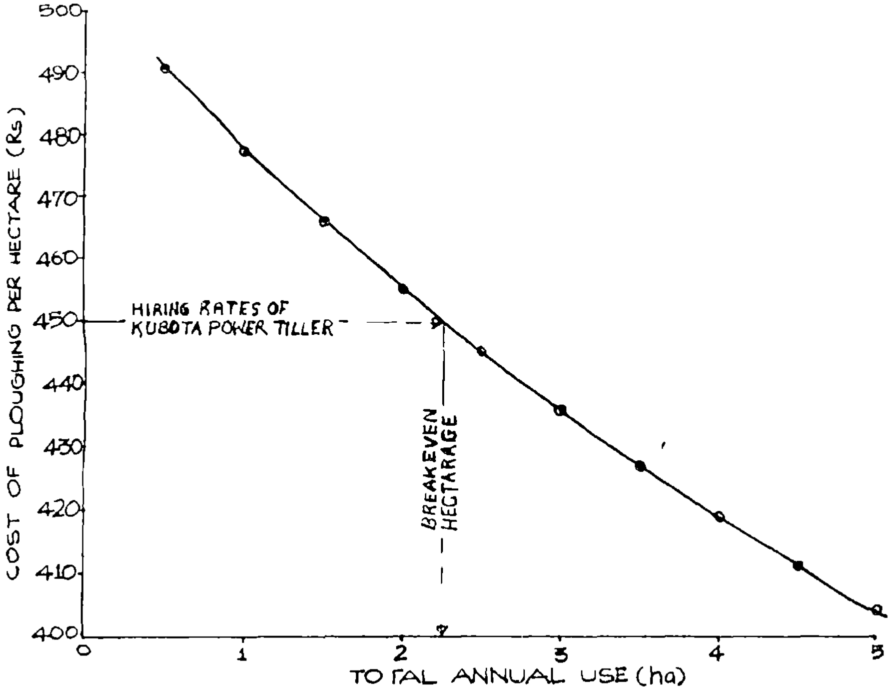


Fig 17 COST OF PLOUGHING Vs TOTAL ANNUAL USE

The relation between cost of ploughing per hectare and total area ploughed is shown in Fig.17. As the total area ploughed increases, the total annual use of the machine also increase and this is the reason for decrease in cost of ploughing per hectare.

The hiring rates of Kubota power tiller for the same operation will amount to Rs.450.00 per hectare. Therefore, from the figure, it is seen that the break even hectarage of garden tractor compared to hiring of Kubota power tiller is 2.24 hectares.

Summary

SUMMARY

Small, power operated and low cost agricultural machines are most suited for Indian farms. Kerala Agricultural University had developed a 5.4 hp diesel powered low cost garden tractor. Considering the advantages of rotary tillers over non powered tillage tools, and in order to make the KAU garden tractor a versatile farm power unit, it was decided to undertake the study of development of a rotary tillage attachment to the garden tractor.

The rotary tillage attachment consists of mainframe, power transmission system, blade assembly, hitching mechanism and protective cover.

The mainframe is fabricated with mild steel flat of 50 x 10 mm size and it holds the blade assembly, the power transmission elements and the protective cover.

Power from the intermediate shaft of the garden tractor is first brought to the idle shaft which revolves at the rear hitch point and from there it is taken to the rotor shaft. Two stage chain and sprocket power transmission system was so designed to get a rotor speed of 290 rpm corresponding to a forward speed of 3.5 kmph.

Twelve blades eacn of 3 cm width are bolted on a hollow shaft of 5 cm external diameter and 1 cm thickness to form the blade assembly.

The hitching mechanism holds the mainframe firmly to the chasis and enables the blade assembly to work as a fully mounted unit of the garden tractor.

The protective cover protects the operator from flying stones and clods and prevents the soil from being thrown over standing crops.

Weight of the rotary tillage attachment is 30.5 kg and the total weight of the garden tractor along with rotary tillage attachment is 175.5 kg.

The centre of gravity of the garden tractor along with rotary tillage attachment is located at 22 mm ahead of the ground wheel axle and 450 mm above the ground level.

The implement penetrates to a depth of 10 to 15 cm and covers a width of 30 to 32 cm in the field. An effective field capacity of 0.054 ha per hr is possible at a field operating speed of 2 kmph.

The fuel consumption at a field operating speed of 2 kmph is found to be 0.860 l per hr.

A single operation of the implement produced a tilth which is nearly equivalent to two operations of tractor drawn spring loaded cultivator and to one operation of Kubota power tiller with rotavator.

The cost of production of the rotary tillage attachment is Rs.1500.00. The cost of ploughing per hectare decreases as the total annual use increases. On an average, the cost of ploughing per hectare can be taken as Rs.450.00.

Further improvements on the rotary tillage attachment of the garden tractor may be attempted by (a) replacing the gun metal bushes of the cutter drum shaft with sealed bearings, (b) enclosing the chain drives and (c) providing a separate clutch for disengaging the rotary tillage attachment when it is not in work.

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ABSTRACT

Considering the advantages of rotary tillers over non-powered tillage tools, and in order to make the KAU garden tractor a versatile farm power unit, a rotary tillage attachment for the garden tractor was developed and tested. The main components of the rotary tillage attachment are mainframe, power transmission system, blade assembly, hitching mechanism and protective cover. The depth of tillage obtained is 10 to 15 cm and the effective width of field coverage is 30 to 32 cm. The actual field capacity of the machine is 0.054 ha per hr and the quantity of fuel required to operate the machine is 0.860 l per hr. Operator can easily walk behind the rotary tiller and turn the garden tractor to either side. The cost of production of the rotary tillage attachment is Rs.1500.00 and the total cost of ploughing per hectare using the machine is Rs.450.00.

Appendices

Appendix I

Design of chain and sprocket in the first stage

The required transmission ratio is 1.8125 as discussed under 3.1.2. The number of teeth in the sprocket penion, (Z_1) is taken as 15 which is higher than the minimum required. Hence the number of teeth in the sprocket wheel,

$$Z_2 = 15 \times 1.8125 = 27.1875 \simeq 27$$

Hence the speed of rotation of the idle shaft is

$$\frac{160 \times 27}{15} = 288 \text{ rpm.}$$

Chain with pitch (P) 12.70 mm is selected.

Pitch diameter of sprocket penion,

$$d_{p1} = \frac{12.70}{\sin(180/15)} = 61.08 \text{ mm}$$

Tip diameter of sprocket penion,

$$d_{a1} = 61.08 + (0.6 \times 12.70)$$

$$= 68.70 \text{ mm}$$

Pitch diameter of sprocket wheel,

$$d_{ps} = \frac{12.70}{\sin(180/27)} = 109.40 \text{ mm}$$

Tip diameter of sprocket wheel,

$$d_{a2} = 109.40 + (0.6 \times 12.70)$$

$$= 117.02 \text{ mm}$$

Centre distance between the intermediate shaft and idle shaft is 490 mm.

Cetre distance in multiple of pitchi,

$$Cp = \frac{490}{12.70} = 38.58$$

Length of the continuous chain in multiples of pitch

$$= 2\,(38.58) + \frac{(15+27)}{2} + \frac{\left(\frac{27 - 15}{2}\right)^2}{38.58}$$

$$= 98.25$$

It is approximated to the even number, 100. Henced a chain tightner is required at the sag side.

A chain with specification, ISO/DIN 084-1 R 1248 H is selected, for which the minimum breaking load is 1600 kgf.

Appendix II

Specification of ISO/DIN 084-1 Rollen R 1248 H chain

Pitch	=	12 70 mm
Rollder dia max	=	7.75 mm
Width between inner plates	=	4.90 mm
Pin body dia, max	=	4.09 mm
Plate depth, max	=	11.10 mm
Bearing area	=	36.00 mm^2
Weight per metre	=	0.58 kgf
Breaking load, min	=	1600 kgf

Appendix III

Teeth specifications of sprockets

Pitch	=	12.70 mm
Roller dia, max	=	7.75 mm
Width between inner plates	=	3.30 mm
Tooth width, min	=	2.79 mm
Tooth width, max	=	2.97 mm
Tooth side radius	=	12 70 mm
Side relief	=	0.89 mm
Shroud depth, min	=	2.16 mm
Shroud radius max	=	0 76 mm

Appendix IV

Design of chain and sprocket in second stage

The transmission ratio required in the second stage is unity. Therefore two sprockets, each having 15 teeth were taken.

Pitch diameter of the sprockets,

$$dp = \frac{12.70}{\text{Sin}\ (180/15)}$$

$$= 61.08 \text{ mm}$$

Tip diameter of the sprockets

$$da = 61.08 + (0.6 \times 12.7)$$

$$= 68.70 \text{ mm}$$

Centre distance between the idle shaft and rotor shaft is 395 mm.

Centre distance in multiples of pitch,

$$Cp = \frac{400}{12.70} = 31.10$$

Length of the continuous chain in multiples of pitch

$$= 2\ (31.10) + \frac{(15+15)}{2} = 77.2$$

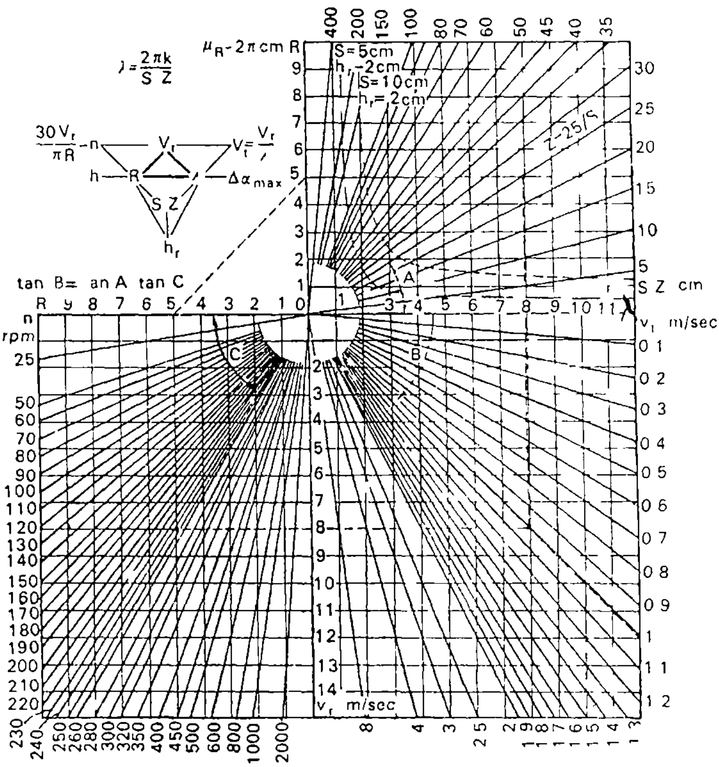
It is approximated to the even number 78. Hence a chain tightner is required at the sag side.

ISO/DIN 084-1 R1248 H chain is selected for which the minimum breaking load is 1600 kgf.

Appendix V

Nomograph for calculating parameters and working

regimes of rototillers



DEVELOPMENT AND PERFORMANCE EVALUATION OF A ROTARY TILLAGE ATTACHMENT TO THE K.A.U. GARDEN TRACTOR

By

JOSE C. M.

ABSTRACT OF A THESIS

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Kerala Agricultural University

Department of Farm Power Machinery and Energy
Kelappaji College of Agricultural Engineering and Technology
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1990

ABSTRACT

Considering the advantages of rotary tillers over non-powered tillage tools, and in order to make the KAU garden tractor a versatile farm power unit, a rotary tillage attachment for the garden tractor was developed and tested. The main components of the rotary tillage attachment are mainframe, power transmission system, blade assembly, hitching mechanism and protective cover. The depth of tillage obtained is 10 to 15 cm and the effective width of field coverage is 30 to 32 cm. The actual field capacity of the machine is 0.054 ha per hr and the quantity of fuel required to operate the machine is 0.860 l per hr. Operator can easily walk behind the rotary tiller and turn the garden tractor to either side. The cost of production of the rotary tillage attachment is Rs.1500.00 and the total cost of ploughing per hectare using the machine is Rs.450.00.